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and
Atmospheric Electricity

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VOLUME 52 MARCH, 1947 No. 1

ECHOES AT *D*-HEIGHTS WITH SPECIAL REFERENCE TO THE PACIFIC ISLANDS

BY C. D. ELLYETT

Summary—Radio echoes obtained from an equivalent height of 50 km above Pitcairn Island by the usual vertical incidence pulse technique are attributed to *D*-layer reflections. Previous literature has been collected, and many conflicting statements on the occurrence and behaviour of *D*-layer echoes are revealed.

A total of 1302 observations of the layer, taken at Pitcairn Island between October 1, 1944, and November 16, 1945, have been analysed, showing:

(i) A frequency-range largely contained between 2.5 and 5.0 Mc;
(ii) Occurrence during 65 per cent of all daytime observations, although night occurrence is not excluded;
(iii) Both a summer and a winter minimum of activity;
(iv) A strength of approximately one-third the *E*-layer-echo strength, and all the typical characteristics of a sporadic region.

Similar echoes have been reported from Raoul Island (Kermadec Group) during approximately 75 per cent of the daytime in the summer of 1944–45, and from Christmas Island during 87 per cent of the daytime in the period June 11–30, 1945. It is considered that the echoes may be characteristic of a tropical region.

§1. *Introduction*

Scattered throughout ionospheric literature repeated reference is made to echoes observed at an equivalent height of approximately 50 km. These reflections, which are distinct from the *D*-region non-deviative absorption at about the same height, are now usually called *D*-layer echoes. Some earlier articles describe such echoes as from *C*-layer, but in this article all reflections of 50 km and above will be described as *D*-layer, the old terminology being changed where necessary.

Many conflicting statements occur in the literature associated with *D*-echoes. The purpose of this paper is to bring together the scattered earlier results, describe a new feature which has become apparent from a large number of results collected at Pitcairn Island during 1944 and 1945, and point out those properties of the *D*-layer which still remain largely unknown.

TABLE 1—*Ionospheric results reported in the literature*

Reference	Date	Period of year	Local time D observed	Observing interval	Method of observation	Frequency	Place	No. of times observed	Height	Strength
						Mc/s			*km*	
1	March, 1927, and later		Day only starting 1 hour after sunrise		Frequency-change, oblique	0.75	England	Many days	60	
2	1930		After sunrise		Frequency-change, oblique		Australia (Sydney)		60 approx.	Very weak
3	Feb. to April, 1934		Especially after sunset	Continuous	Vertical pulse	3.5	Canada (Montreal)	On 4 days	50	Weak
4	April 1935	Observed in summer	Between $15^h\ 00^m$ and $17^h\ 00^m$		Vertical pulse		India (Calcutta)	3	55	As D increases E weakens
5	(1936)				Vertical pulse	1.6 and 3.5	America			As D increases E and F weaken
6	(1936)	More likely in winter			Vertical pulse		America			
7	(1936)				Vertical pulse		England		60	
8	June, 1936		Day and night (more likely in afternoon)	1½ hours	Vertical pulse	Noon freq. max. thus solar origin	India			Day always weaker than night; weak about midday; night sometimes equal to E and F
9	(1936)		Night very unlikely		Vertical pulse	2.1	India		55	
10	(1936)	Summer and winter	More about $16^h\ 00^m$ than noon		Vertical pulse		India (Calcutta)	Many occasions	55	
11	Jan. 16, 1937		$07^h\ 40^m$ to $16^h\ 45^m$ contin.	Continuous	Field-intensity recorder, oblique	1.0,	America (Hartford)	One day		
12	(1937)	No large seasonal variation	Day or night		Vertical pulse	6.0 and higher	England			Equiv. reflection coeff. = 0.3 at 6 Mc/s
13	(1937)				Vertical pulse	1.6, 2.4, 3.5	America (Virginia)	Occasional	15 to 65	
14	(1939)		Day or night		Vertical pulse	1.6	America (Virginia)	Frequently	Variable	
15	(1939)				Vertical pulse	8.8	England (south-east)			Very weak equiv. reflection coeff. (0.0005). May be due to latitude of station
16	July 8-10, 1945		Day and night	Every minute	Oblique Loran	2.0	Newfoundland			
17	March to June, 1945		Daytime between $09^h\ 00^m$ and $17^h\ 00^m$	Mainly ½ hour	Oblique Loran	2.0	Australia (near Darwin)	140 times in June	65 to 70	Usually weak
18	June 11-30, 1945		Daytime always (absent most frequently near noon; no diurnal trends)	134 observations	Vertical pulse (manual)	Strongest at 2.0 (not above 2.5; f_D max. never exceeded f°_E)	Central Pacific (Christmas Island)	116 times	55 to 65	Weak. Great day-to-day and hr.-to-hr. variations.

§2. *Previous observations of D-echoes*

The fact that *D*-echoes have been reported at various times over the past twenty years from seven widely separated countries, with different observers and equipment, makes it fairly certain that such echoes are of real world-wide occurrence. However no long-term consistent series of observations appears to have been undertaken. The various results reported in the literature have been assembled in Table 1. Where the actual date of the observations is uncertain the year of publication only has been given, enclosed in parentheses.

From Table 1 it will be seen that the minimum equivalent height is generally between 50 and 65 km. Also the frequency-range in which the echoes occur lies mainly between 1.0 and 3.5 Mc/s, although they have been reported outside these limits. The echoes appear to be of a sporadic nature, showing day-to-day and hour-to-hour variations [see 18 of "References" at end of paper] and appearing conjointly with higher-layer echoes [4, 5, 10, 18]. However in the following four respects there is a considerable divergence of evidence:

- (i) *The diurnal time of occurrence*—Seven articles report daytime occurrence only, and one reports that night time is extremely hypothetical. As against this one reports occurrence especially after sunset and four report day or night occurrence.
- (ii) *The annual time of occurrence*—Of the three articles which mention the annual change, all imply that *D*-echoes can occur throughout the year, but it is qualified in one case by a preference for winter, and in another case no large variation is found.
- (iii) *The strength of echoes*—Five cases report the echoes as weak or very weak. A sixth reports the day as invariably weaker than the night, when the signals are sometimes very strong; whilst a seventh obtains quite a moderate echo-strength. Two other observers state that as *D*-strength increases *E*-strength weakens.
- (iv) *The character of the layer*—Two papers [11, 17] indicate that at frequencies above approximately one Mc the *D*-echoes are sporadic in character, whilst at frequencies of the order of 450 kc a truly refracting layer is found; but other evidence [15] considers this to be unlikely, and that the region is one of scattered patches.

Further experimental information on the first three of these topics has now been obtained, but no low-frequency experiments have been carried out which would help to elucidate the character of the layer.

§3. *Pitcairn Island observations*

It was decided in 1944 to set up a low-power manual ionospheric station at Pitcairn Island (latitude 25°.0 south, longitude 130°.0 west) in conjunc-

tion with other radio equipment then being maintained at the Island. The width of the transmitted pulses was approximately 150 microsec. The transmitting aerial was a six-wire-cage type erected in two sections 66 feet in length and 35 feet high, center fed by a 600-ohm open line 130 feet in length. The receiving aerial was an inverted L-type 100 feet in length, 70 feet high and running almost parallel to the transmitting aerial at a distance of 100 feet. The station itself was 800 feet above sea-level.

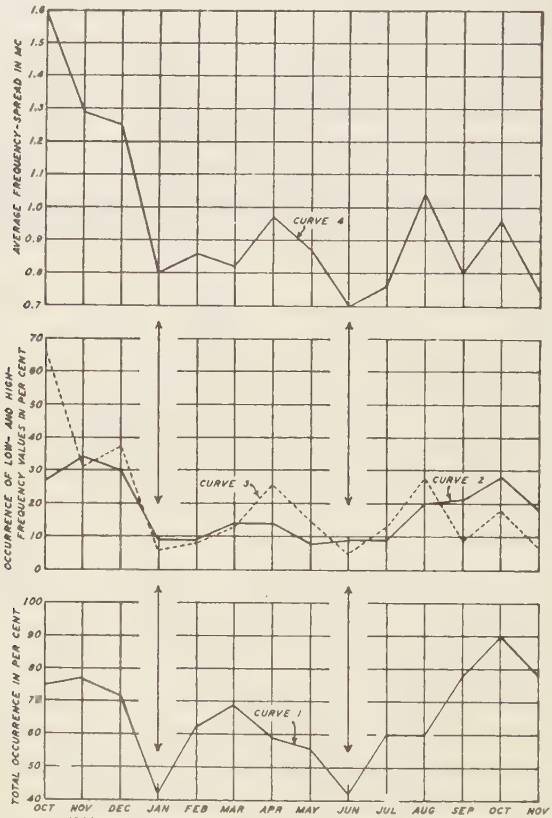

FIG. 1—MONTHLY OCCURRENCE OF D PHENOMENA, 07^h30^m–15^h30^m, INCLUSIVE

Five observers of the New Zealand Post and Telegraph Department were available, enabling vertical $h'f$-curves to be plotted nine times per day. The operators were largely unskilled in ionospheric recording and interpretation, and so the observing period per record was at least ten minutes. The procedure was for all echoes to be plotted as carefully as

possible, and for the records subsequently to be analysed in the Christchurch Ionospheric Laboratory of the Department of Scientific and Industrial Research, New Zealand.

Observations were taken at $02^h\ 30^m$, $05^h\ 30^m$, $07^h\ 30^m$, $09^h\ 30^m$, $11^h\ 30^m$, $13^h\ 30^m$, $15^h\ 30^m$, $19^h\ 30^m$, and $22^h\ 30^m$ daily (127°.5 MMT) between October 1, 1944, and November 16, 1945. Over the whole period one case of *D*-echo was observed at each of the three hours $05^h\ 30^m$, $19^h\ 30^m$, and $22^h\ 30^m$. For the purpose of further analysis these three cases have been eliminated. All other observations of *D* occurred in the daylight hours between $07^h\ 30^m$ and $15^h\ 30^m$ inclusive, and out of a total of 1994 observations between these hours, *D* was recorded on 1302 occasions, or 65.3 per cent of the time.

It was not possible to observe *D* at night because of increased noise level, and interference from short-wave broadcasting stations, making it necessary to turn down the receiver gain controls. Low-strength *D* could have been present but obscured by the higher nighttime noise level.

The following results have been evaluated from the tabulated records. The significance of these results will be discussed in §4 below.

(*a*) *Monthly percentage of time-occurrence of D-echoes for all observations between* $07^h\ 30^m$ *and* $15^h\ 30^m$ (*MMT*), *inclusive*—The percentage occurrence is shown in Curve 1 of Figure 1. There is pronounced evidence of both a summer (January) and a winter (June) minimum. Alternatively the curve may be regarded as showing very nearly equinoctial maxima. In November, 1945, the station closed after the 16th of the month. If the rate of occurrence is falling as indicated, then over the whole month the average figure should be still lower than is shown by the graph.

As a number of different observers were taking observations, it is important to establish to what extent the shape of Curve 1 is influenced by the results of individual observers.

Each observer took between 30 and 40 observations per month on the hours stated, with the exception that J. W. Carlisle took only 20 when he started in August. Observing schedules were continually altered, so that the results of any single observer were scattered fairly uniformly through the hours of the day and the days of the month.

The results are given in Figure 2, from which the following facts emerge:

(i) The minimum extent of echo which has to be present to be recorded as *D* obviously varies with different observers, for example, N. D. Dyett and L. Hack record a consistently higher percentage than L. Young.

(ii) Of the four observers in June, three record the June minimum, and the fourth records a negligible rise. All five observers record the September-October rise and the November fall. It would thus seem clear that the combined curve of Figure 1 is authentic.

(iii) The combined value for August is the same as for July. However two observers show a falling trend and one a rise. J. W. Carlisle recorded D in only 3 out of 20 observations, but showed a very big rise up to the level of the other observers in September, possibly as he became more familiar with the picture. His results would thus tend to depress August. On the existing evidence it is not possible to state clearly the value for August in relation to July.

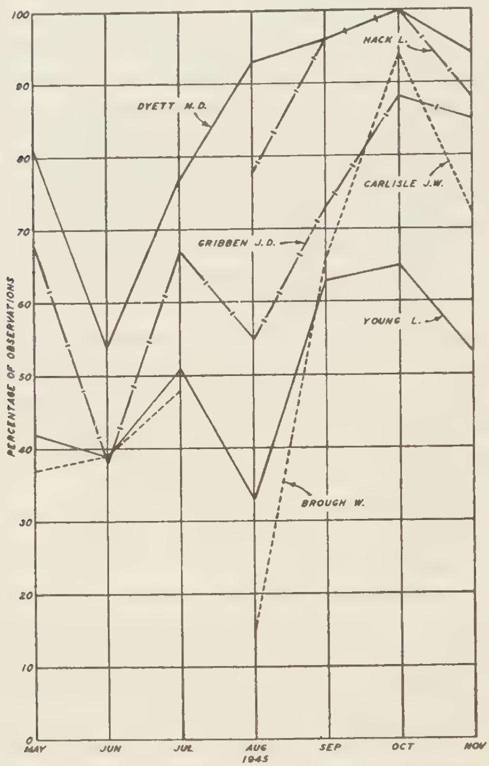

FIG. 2—INDIVIDUAL OBSERVERS: PERCENTAGE OF OBSERVATIONS SHOWING D, 07^h30^m–15^h30^m, INCLUSIVE

(The legend "Brough W." should be against the short dotted line between May and July at left side.)

(*b*) *Weekly percentage of time-occurrence of D-echoes for all observations between* $07^h\ 30^m$ *and* $15^h\ 30^m$ (*MMT*) *inclusive*—These results are given in Curve 1 of Figure 3. Many pronounced weekly fluctuations are apparent.

(*c*) *Hourly percentage of time-occurrence of D-echoes*—The hourly percentage occurrence for each month is given in Table 2.

TABLE 2—*Hourly percentage of D-occurrence*

Month	$07^h\,30^m$	$09^h\,30^m$	$11^h\,30^m$	$13^h\,30^m$	$15^h\,30^m$
October 1944	37	83	89	*87*	*82*
November	*43*	*93*	*100*	*87*	62
December	31	81	92	79	75
January 1945	16	58	48	50	37
February	14	57	85	*96*	57
March	*23*	*74*	*93*	86	*70*
April	20	57	87	80	53
May	21	68	84	60	47
June	0	47	72	59	35
July	13	74	80	86	52
August	23	58	81	77	65
September	43	90	83	93	80
October	*77*	*97*	90	90	*94*
November 1945	56	81	88	*94*	69
Hourly average	30	73	83	79	63

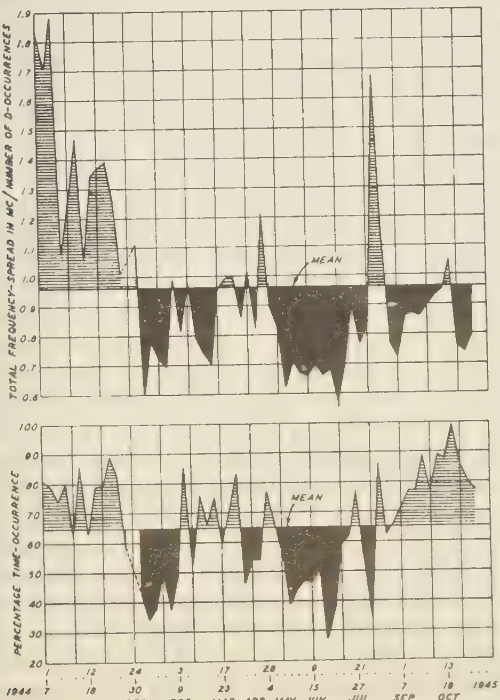

FIG. 3—WEEKLY AVERAGE VALUES OF D-ECHOES, 07^h30^m–15^h30^m, INCLUSIVE

The particular hours at which D is recorded vary in a random fashion from day to day, but in general the greatest number of observations occur at midday, falling off symmetrically on either side of that time. When treated by individual hours the maxima—which are shown in italics in Table 2—again fall close to the equinoctial periods.

The hourly percentage occurrence recorded by individual observers was also investigated. For the period May, June, July, 1945, which is of low activity, all observers without exception followed the shape and value of the diurnal curve very closely. However, for the period September, October, November, 1945, of greater activity there was a considerably greater individual divergence, particularly at $11^h\ 30^m$ when two observers recorded a minimum not found by the other three.

(*d*) *Maximum frequency of D-echoes*—A critical frequency was not observed, the layer merely fading out in the same fashion as sporadic E. The receiver was divided into four bands, with the change from Band 2 to Band 3 occurring at about 4.2 Mc. There was obviously a change in set-sensitivity at this point, for in *every* month the maximum D-frequency of 4.2 Mc was more prominent in quantity than any other frequency. Also Es-echoes frequently terminated at 4.2 Mc. A hystogram showed that $f_{D_{max}}$ was largely contained between 3.3 and 5.0 Mc, with a maximum occurrence about the middle. However the exact maximum occurrence was obscured by the fact that the 4.2-Mc value occurred more than twice as frequently as any other invididual value. Record interpretation was possible to an accuracy of ± 0.1 Mc.

(*e*) *Monthly fraction of D-observations exceeding 4.2 Mc*—Those D-echoes which do exceed 4.2 Mc are therefore showing on a less sensitive part of the receiver scale and thus are the stronger echoes. The monthly number of times echoes were observed on 4.3 Mc or greater, expressed as a percentage of the total observing hours between $07^h\ 30^m$ and $15^h\ 30^m$ inclusive (see Curve 2, Fig. 1). Although these maximum frequency-observations are not directly connected with the percentage time-occurrence of D-echoes, the same January and June minima appear. The actual number of occurrences above 4.2-Mc ranges from 51 in November 1944 to 12 in May 1945.

(*f*) *Monthly fraction of D-observations below 3.0 Mc*—The lowest frequency at which D-echoes were observed lay predominantly between 3.0 and 3.9 Mc with the monthly median consistently 3.2 Mc. This value is significant in being the start of Band 2 of the transmitter. The monthly percentage of time-occurrence of echoes below 3 Mc, and therefore on Band 1 of the transmitter and presumably with a weaker radiated pulse, is shown as Curve 3 of Figure 1. Once again pronounced January and June minima appear. The curve is somewhat more random than Curves 1 and 2, and a subsidiary minimum appears in September.

(*g*) *Monthly average frequency spread of D-echoes*—If the individual records in which D is observed to commence at a low frequency are also those which show a high upper frequency, then the spread of frequency over which D-echoes are recorded should be approximately the addition of Curves 2 and 3 of Figure 1, and should be of the same shape. This was found to be the case. The total monthly frequency-spread, divided by the number of times D was observed during the five daylight hours of observing throughout the month, is given by Curve 4 of Figure 1.

An hourly analysis was also made which showed that for the whole observing period there was little to choose in frequency-spread between $09^h\ 30^m$, $11^h\ 30^m$, and $13^h\ 30^m$, but that on these hours the spread was definitely greater than either $07^h\ 30^m$ or $15^h\ 30^m$.

(*h*) *Weekly average frequency-spread of D-echoes*—These results, calculated in the same way as for the monthly spread, are given in the upper Curve of Figure 3. The general similarity between the two curves in Figure 3 is pronounced.

(*i*) *Miscellaneous observations*—As far as possible the spread in height of D-echoes was shown on each $h'f$-record. The home pulse occupied 35 km of the time-base. The D-echo generally commenced at 50 km but was lower on a very few occasions, showing that the receiver could record below 50 km. In the great majority of occasions the D-echo was spread, frequently penetrating through the Es-level on the oscillograph-picture. The percentage of D with a height spread above 100 km was practically constant with time of day. The monthly variation was not pronounced. No summer change was observed, but the winter spread generally was greater than summer, although there was a definite winter decrease in June.

From August 18 to the conclusion of observations visually observed average signal-strengths of both D- and E-echoes (including Es) were recorded on an arbitrary scale ranging from 1 for very weak to 5 for very strong echoes. On this scale the main bulk of D-echoes was of strength $1\frac{1}{2}$ or 2, while E-echoes were of strength 3 or $3\frac{1}{2}$.

When the D-strength was $\leqq 1\frac{1}{2}$ (160 cases), 46 per cent of E-echoes exceeded strength 3, and when D-strength was $> 1\frac{1}{2}$ (184 cases), 52 per cent of E-echoes exceeded strength 3. Thus as D-strength increases there is a very slight *increase* in E-strength. This increase may be within the experimental error, but at least D-echoes do not appear to reduce higher-layer amplitudes appreciably.

With rising frequency the D-echoes sometimes commenced strongly and at other times slowly increased in amplitude from a small beginning. At the upper limit the D-echoes became gradually weaker, while the higher-layer echoes maintained their strength, showing that the fall in D-strength was not a function of the equipment.

At all times the D-reflection behaved like any spread echo in showing

rapid irregular height pulsations, with different sections fading independently

§4. *Conclusions from Pitcairn Island results*

(i) *D*-echoes have only been observed during daylight hours, although their existence at night cannot be completely ruled out. The echoes appear to be most numerous around midday, in agreement with the later workers [11, 17, 18].

(ii) The main fact emerging is the definite minimum of *D*-activity in both midsummer and midwinter. This result is at variance with earlier work [6, 12]. Although the percentage of time-occurrence, the percentage of high and low frequencies, and the average frequency-spread, are separately recorded phenomena (Fig. 1), they are not necessarily entirely disconnected. A certain minimum echo-strength is necessary to be recorded at all. Such an echo—due to set characteristics—is likely to be observed over a very small frequency-range. Then as the strength increases the echo is likely to spread out in frequency-coverage. Thus the variables considered are all in part determined *by the strength of the echo.*

The similarity between the curves of Figure 1—particularly the lower one—and monthly noon f^0F2-curve for most Southern Hemisphere ionospheric stations is pronounced. It is not safe however to generalize from only one year's observations of *D*. If the same trend could be established for a second year it would be of considerable theoretical interest, as layers at both the top and the bottom of the ionosphere would then be behaving similarly. Unfortunately in the present instance Pitcairn Island alone amongst 14 stations in the Southern Hemisphere appears to be anomalous in showing only the slightest evidence of a midsummer dip in monthly noon f^0F2 during January-February 1945, although a marked winter minimum occurs in July.

(iii) It has been stated [18] that $f_{D max}$ never exceeds f^0E, but support for this is not obtained from the Pitcairn Island results, where $f_{D max}$ frequently exceeds f^0E and appears to be entirely separate from it in behaviour.

Likewise, knowing the symmetrical diurnal behaviour of f^0E, an analysis for each of the five observing hours of the number of occasions on which $f_{D min}$ exceeds f^0E showed that $f_{D min}$ was unconnected with f^0E.

(iv) Usually the *D*-echoes have appreciable strength, perhaps 1/3 to 1/2 that of the *E*-echoes. This picture agrees with most of the reported results [2, 3, 12, 17, 18], but not with the extreme weakness quoted by J. H. Piddington [15], nor with the diurnal-strength variation discussed by H. Rakshit and J. N. Bhar [8].

(v) Two previous observers [4, 5] report that as D-strength increases E-strength is correspondingly weakened. Such was not found to be the case with the present results (see §3).

(vi) At $11^h\ 30^m$ on December 10, 1944, D appeared to be very strong, covering the range from 2.2 to 6.1 Mc, and blanketed E- and $F1$-echoes completely, and also the lower part of the $F2$-echo up to 5.5 Mc. On several occasions D has continued beyond fEs_{max}, and again in one case D was present, as well as strong Es which blanketed $F1$ and $F2$ completely. D has also occurred commonly without Es being present. These facts, as well as the evidence in §3, are consistent with the idea that D is a sporadic ionization, at least within the range from 1.5 to 12 Mc covered by the equipment.

There is no possibility that echoes could have been obtained from land masses, as Pitcairn Island itself is very small, and the only other nearby land is Oeno Island, 65 miles northwest of Pitcairn, which is only a few feet above water level, and Henderson Island, 105 miles east-northeast of Pitcairn.

(vii) A correlation was looked for connecting the weekly fluctuations of D-occurrence as shown in Figure 3, first with magnetic K-indices and secondly with the central meridian passage of sunspots possessing magnetic fields greater than 1000 gauss, but with negative results. A connection is possible with ozone formation [19, 20] or even with barometric fluctuations caused by temperature changes [21], but correlations with these phenomena are not likely to be reliable with the limited data available, and have not been attempted.

§5. *Occurrence of D-echoes at Raoul Island (30°.0 south, 178°.0 west)*

Information here is twofold. First a short statement written in April, 1944, [22] described a few isolated cases of D-echo in July, 1943, reappearance on two or three days of January, 1944, 14 days in February on seven of which it was persistent, and 13 days up to March 26 on nine of which it was persistent. The layer appeared only in daylight hours and resembled Es in showing a maximum and not a true critical frequency. Its presence did not appear to affect the occurrence of Es. Normally the frequency did not exceed 4.3 Mc, and the equivalent height was between 60 and 80 km.

Secondly discussions were held with three observers on their return from Raoul Island in 1945. These observers were entirely independent of the Pitcairn Island group. Although D was not systematically recorded at Raoul Island it was frequently observed, and the following facts were stated.

(i) The height was in the region 50-60 km. No accurate estimate of height could be made below 50 km due to set limitations.

(ii) *D* usually appeared about two hours after sunrise and disappeared about two hours before sunset.
(iii) *D* was often present at the minimum frequency of the equipment, namely, 1.8 Mc. The upper frequency-limit was usually between 2.5 and 5 Mc, although occasionally it was much higher.
(iv) *D* was present on 75 to 80 per cent of summer days, and appeared to a lesser extent in winter.

These conclusions fit in closely with the Pitcairn Island results.

§6. *Extent of D-echoes*

D-echoes have been observed independently for 65 per cent of the daytime over one year at Pitcairn Island, 87 per cent of the daytime during June 11-30, 1945, at Christmas Island in the central Pacific [18], and for an estimated 75 per cent of the summer daytime period of 1944-45 at Raoul Island. A phenomenon appearing to this extent must have a real existence. Such echoes have been looked for on the 1-kw Christchurch (New Zealand) ionosphere transmitter but have only been seen clearly on one occasion. It is possible therefore that these echoes are more persistent in tropical regions than in higher latitudes such as New Zealand or England. The possibility also must not be overlooked that there may be a variation in signal-strength of *D*-echoes connected with the solar sunspot-cycle.

During the period of observation at Christmas Island when *D* was recorded on 87 per cent of the time, *D* was recorded on only 39 per cent of the time at Pitcairn Island. The difference could be accounted for by a difference in power of the sets at the two islands. Before any real progress can be made in correlating the occurrence at different stations it will be necessary to know the absolute amplitude of the received echoes, since at the present time unknown changes in noise level over the year may introduce spurious fluctuations of *D*-occurrence.

Acknowledgments—The data on which this paper is based have been collected as part of the program of ionospheric observations of the New Zealand Radio Research Committee. The equipment was constructed by the New Zealand Department of Scientific and Industrial Research, and the field-work at Pitcairn carried out by the New Zealand Post and Telegraph Department.

The author wishes to acknowledge the helpful cooperation given by D. A. C. Shepherd, New Zealand Post and Telegraph Department, as Officer-in-Charge of the Pitcairn Station. Acknowledgment is also made of the careful work of the teams of observers at Pitcairn and Raoul islands, who made this article possible.

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Canterbury University College.
Christchurch, New Zealand, February 3, 1947

(See also pages 65, 76, and 80)

PROVISIONAL SUNSPOT-NUMBERS FOR OCTOBER TO DECEMBER, 1946

(Dependent alone on observation at Zürich Observatory)

Day	October	November	December
1	91	95	84
2	107	88	88
3	73	85	79
4	77	59	104
5	55	88	102
6	64	121	93
7	67	125	111
8	65	126	87
9	57	128	73
10	61	130	103
11	50	138	119
12	68	169	127
13	92	131	99
14	144	167	116
15	115	145	165
16	131	140	150
17	126	159	143
18	127	154	143
19	134	166	141
20	131	141	145
21	128	141	126
22	133	124	138
23	132	153	147
24	123	140	152
25	136	138	148
26	128	127	145
27	130	116	144
28	106	102	154
29	109	84	132
30	102	69	116
31	103		98
Means........	102.1	125.0	121.7
No. days......	31	30	31

Mean for quarter October to December, 1946: 116.2 (92 days)
Mean for year 1946: 92.4 (362 days)

Swiss Federal Observatory,
Zurich, Switzerland

M. Waldmeier

AMERICAN MAGNETIC CHARACTER-FIGURE, C_A, THREE-HOUR-RANGE INDICES, K, AND MEAN K-INDICES, K_A, FOR OCTOBER TO DECEMBER, 1946, AND SUMMARY FOR YEAR 1946

By W. E. Scott

Summaries of American *URSI* broadcasts have appeared regularly in this Journal since the issue for December, 1930.

As set forth in this Journal for June, 1937, "The Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey with the cooperation of the United States Army and the United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, the second twelve, and all twenty-four hours of each Greenwich day for October to December, 1946, are given in Table 1.

From April 6, 1940, to November 28, 1941, American *URSI* broadcasts gave three-hour-range indices, K, for each of the seven American-operated observatories. Since November 28, 1941, the indices have been supplied by the Department of Terrestrial Magnetism in "Weekly reports on geomagnetic activity" directly to organizations or individuals with legitimate needs which were compatible with the war emergency. The eight indices for each day give geomagnetic activity for three-hour periods successively during the Greenwich day. The indices range from "zero" very quiet to "nine" extremely disturbed. The K-indices for Sitka (Si), Cheltenham (Ch), Tucson (Tu), San Juan (SJ), Honolulu (Ho), Huancayo (Hu), and Watheroo (Wa), for October to December, 1946, are given in Table 2. Interpolated indices are shown thus: $\ddot{3}$.

In the manner set forth in the Journal for September, 1940, the indices are standardized into reduced indices K_r to eliminate local variations. A weighted mean index, K_A, is derived from the reduced indices. The reduced indices from Si, Ch, and Wa are given double weight and those from Tu, SJ, Ho, and Hu are given single weight. The weighted indices, K_A, for October to December, 1946, are given in Table 3. A superior cross ($^\times$) following an index-number denotes a half-unit, thus $5^\times = 5.5$, etc.

The mean ratings of the American magnetic character-figure for each half-day by months during 1946, for the individual observatories, appear in Table 4. The average activity for the year was 0.36, reflecting the slight increase in activity following the two recent quiet years of 1944 and 1945 with average activity of 0.29 and 0.25, respectively. Despite the fact that

Table 1—*American magnetic character-figure C_A for Greenwich half- and full-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for October to December, 1946*

Day	October			November			December		
	00^h-12^h	12^h-24^h	00^h-24^h	00^h-12^h	12^h-24^h	00^h-24^h	00^h-12^h	12^h-24^h	00^h-24^h
1	0.6	0.5	0.5	0.8	0.8	0.8	0.0	0.2	0.1
2	0.2	0.2	0.2	0.4	0.0	0.2	0.0	0.3	0.1
3	0.3	0.3	0.3	0.0	0.1	0.0	0.2	0.0	0.1
4	0.4	0.1	0.2	0.0	0.1	0.1	0.0	0.3	0.1
5	0.1	0.6	0.3	0.3	0.7	0.5	0.3	0.5	0.4
6	0.5	0.4	0.4	0.8	0.8	0.8	0.2	0.1	0.2
7	0.5	0.4	0.4	0.1	0.1	0.1	0.3	0.4	0.3
8	0.0	0.4	0.2	0.0	0.1	0.0	0.2	0.0	0.1
9	1.1	0.7	0.9	0.0	0.3	0.1	0.0	0.1	0.0
10	0.1	0.3	0.2	0.0	0.4	0.2	0.1	0.6	0.4
11	0.0	0.3	0.1	0.6	0.2	0.4	0.1	0.6	0.4
12	0.4	0.1	0.2	0.6	0.3	0.5	0.1	0.4	0.2
13	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
14	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
15	0.0	0.1	0.0	0.4	0.5	0.5	0.0	0.0	0.0
16	0.1	0.1	0.1	0.6	0.1	0.4	0.0	0.1	0.1
17	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.1
18	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.2	0.1
19	0.0	0.5	0.2	0.4	0.4	0.4	0.8	0.6	0.7
20	0.9	0.8	0.8	0.1	0.9	0.5	0.0	0.0	0.0
21	0.0	0.4	0.2	1.0	0.6	0.8	0.4	0.2	0.3
22	0.2	0.1	0.1	0.4	0.3	0.4	0.5	0.1	0.3
23	0.1	0.0	0.1	0.3	0.1	0.2	0.2	0.2	0.2
24	0.0	0.1	0.1	0.9	1.0	1.0	0.0	0.1	0.0
25	0.1	0.1	0.1	0.6	0.7	0.6	0.0	0.6	0.3
26	0.6	0.7	0.7	0.2	0.1	0.2	0.3	0.3	0.3
27	1.4	0.9	1.1	0.0	0.0	0.0	0.3	0.2	0.2
28	0.3	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.1
29	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
31	0.1	0.7	0.4				0.0	0.0	0.0
Means	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.2	0.2

the American character-figure averages are lower than the international character-figure, the variations are in close agreement and have proved useful in forecasting because of the tendency of magnetic storms to recur at 27-day intervals.

The American character-figure, C_A, for the period December 12, 1945, to January 1, 1947, is plotted in Figure 1. Its value is shown for each half-day and is arranged in 27-day sequences. The year 1946 is marked by

Table 2--Three-hour-range indices, K, October to December 1946

October 1946

	1	2	3	4	5	6	7	8
Si	3366 5431	2342 5320	1430 4410	1343 2320	0233 6520	1255 2122	1047 5520	1100 0121
Ch	4344 2322	1431 3211	3441 2211	3333 1222	0322 3432	4433 2233	3244 3221	1200 0122
Tu	3354 3332	2432 3322	2431 2321	3333 2232	2322 3432	3333 3234	3234 4232	2320 0233
SJ	3223 1230	0221 3200	2420 1100	3212 1211	1010 3231	2222 2233	3222 2222	2200 2323
Ho	1231 3232	1321 3111	1221 2321	2232 2221	0321 4230	2232 1123	2222 3222	2210 0233
Hu	3222 3442	1221 4421	2321 3411	2112 3432	1222 4542	2332 4333	3221 4442	2211 2333
Wa	2223 4332	1232 4321	1221 3411	2123 2421	2223 5341	2234 2244	2224 3321	2211 0223

	9	10	11	12	13	14	15	16
Si	2666 4333	2114 2121	2200 3221	2430 0112	1101 0000	1032 0110	0013 1121	1034 2112
Ch	3454 3235	2022 2133	3311 3122	4330 0112	3111 0112	1021 1122	0023 1122	1133 2123
Tu	3554 3324	2023 3233	2221 3233	3330 1123	3111 0002	2031 2222	0123 2123	2233 3223
SJ	4444 2334	2012 1232	2212 1332	3320 0011	1100 0001	0020 1111	0021 0112	0122 1103
Ho	4444 2234	2123 1222	2200 1121	2231 0123	1111 0011	1121 1212	0111 1022	1120 0012
Hu	3343 4443	2112 3333	2202 4331	2310 2322	2001 2322	1022 3331	1113 3332	0113 4332
Wa	4545 4234	2123 2242	2211 3322	3331 1121	1121 1001	2122 1321	0123 1113	1223 2222

	17	18	19	20	21	22	23	24
Si	0020 0000	1000 0010	0001 0222	2444 2232	1011 0221	1022 3020	1233 2201	1002 4211
Ch	0130 0121	2100 0012	1101 1134	4333 3343	3111 1233	2132 1111	1332 1111	1011 2121
Tu	2130 0012	2100 0112	1102 2235	5443 4343	2211 1233	3233 3221	1322 2211	1112 3212
SJ	0120 0011	1000 0000	0000 0224	3332 2342	2001 1233	2110 0100	0222 1001	0001 1110
Ho	1120 0021	2100 0001	0101 0134	1332 2243	2100 0133	3122 2111	0121 1011	1101 2122
Hu	1121 2321	1002 3231	1121 3454	3333 5563	2001 2443	2122 2431	1222 3320	0112 3431
Wa	1220 1011	2210 0011	1211 1123	3444 3343	1111 1222	3332 2111	1232 3111	1112 4211

	25	26	27	28	29	30	31	
Si	2144 0101	2355 4334	5698 7532	2343 2220	2124 2121	1123 0200	0033 6431	
Ch	3133 2112	3433 2225	5544 4435	5333 2111	3323 1113	0131 0200	0033 4433	
Tu	2143 2213	3444 3334	5655 5533	3343 2212	3222 2132	1222 0200	0133 3532	
SJ	2022 1101	2422 2234	4453 3423	1211 1211	2002 1112	0011 0101	0023 3422	
Ho	2121 0112	2134 2224	5543 3323	0130 2112	1112 1112	1002 0000	1032 3321	
Hu	1022 3321	2323 4433	3333 5633	2211 2320	2212 2331	1112 2300	0022 5532	
Wa	1112 1322	2233 3335	5435 5524	2132 2311	1114 2221	1121 1101	1133 5432	

November 1946

	1	2	3	4	5	6	7	8
Si	3256 6533	0044 3110	0030 1001	0003 3110	0124 3230	1246 6522	2200 0110	0001 2111
Ch	5545 3223	1141 2112	2030 2101	1003 2112	0123 3333	3335 5423	3411 1110	1001 2113
Tu	3445 3345	2143 1112	1130 1211	1013 2123	1334 4343	3444 5424	4311 2211	1011 1223
SJ	3433 3334	0130 0121	1020 0001	1002 2222	0125 4343	3323 4413	2200 1210	0000 1222
Ho	1224 3423	1232 2011	2110 0112	2002 1123	1124 3343	3333 2323	2200 0100	1000 0012
Hu	2224 5532	1221 3320	1110 3312	1002 4332	0113 5553	3324 7653	3101 3421	0011 3432
Wa	2224 3423	2333 2122	1110 1101	1103 2122	0234 4343	3234 4423	2321 1311	1111 2112

	9	10	11	12	13	14	15	16
Si	2103 2112	2101 1133	3342 1111	1542 1321	0011 1111	0001 2211	0033 2332	2333 3222
Ch	2222 2123	3102 2233	5533 2123	3432 2321	1011 1122	0000 2111	0043 3333	4442 2123
Tu	3122 2234	3211 1234	5443 2334	4442 2433	1121 1223	1001 2212	0054 3433	3433 1223
SJ	2111 2122	2100 1222	3333 1322	2321 0310	0000 0022	0000 0101	0032 3233	3332 1322
Ho	2122 1223	3011 1122	4333 1123	3411 0121	1110 0122	2100 1111	1043 2123	2312 2111
Hu	2112 4432	2112 3444	3324 3433	3222 3541	0112 3442	0002 3331	1033 5643	3322 3322
Wa	2122 2213	3211 2233	3224 2233	3422 2332	4211 1123	1113 2112	0153 3223	3432 2133

	17	18	19	20	21	22	23	24
Si	1200 0111	1023 0000	2444 2323	2210 4332	2127 5322	2543 2311	2334 3111	0345 8422
Ch	2300 1112	2112 2002	3333 2224	2322 3333	4434 4223	4532 1412	3333 2100	0434 6222
Tu	2301 1222	2122 2012	2334 3334	3323 3334	4334 4343	3442 2422	3323 3211	1544 5422
SJ	1101 2211	0013 2212	2233 2224	1123 3433	4244 4233	3321 2301	2222 1100	0433 6321
Ho	1100 1011	1212 1112	2114 1123	1312 4334	5333 2223	2331 0111	1102 2001	1434 5222
Hu	1201 3442	1102 3321	1222 5534	2212 4664	4334 5532	2212 3432	2221 4421	1434 8542
Wa	1111 2112	1222 2102	2134 2325	2323 5322	4345 5333	2222 1312	1112 3112	1544 6322

	25	26	27	28	29	30		
Si	1244 5632	2301 0110	0010 0000	0021 0010	0000 0000	0001 10[illegible]0		
Ch	1324 3433	4410 1210	1000 0000	0230 1001	1000 0001	1001 2101		
Tu	2323 4333	3321 1222	1111 0001	0121 1111	1000 0011	0001 2200		
SJ	1223 3432	2201 2200	0000 0000	0021 1011	2000 0000	0000 1100		
Ho	2332 3322	3200 0201	1000 0011	0021 0012	1100 0011	0100 2100		
Hu	2223 6543	2112 3321	0000 0311	0111 2332	1001 2111	0000 4311		
Wa	3334 4443	2321 2311	1001 0101	1021 1111	1110 1001	1011 3112		

Table 2--Three-hour-range indices, K, October to December 1946--concluded

December 1946

	1	2	3	4	5	6	7	8
Si	0000 0321	1031 3211	2223 2100	0130 2111	0123 3311	2221 1021	2321 1321	1213 1010
Ch	1000 1222	2231 2112	4222 1010	0220 1122	1223 2232	2321 2122	3431 2221	3412 1000
Tu	1000 2231	3121 2223	3233 1111	1220 1132	2233 2333	3321 1123	4431 1322	2312 1101
SJ	0001 1331	1101 0222	2001 1000	0111 1232	3222 2332	2321 2323	2301 2421	2212 0210
Ho	0100 0121	1000 2123	2101 0011	1010 1232	2122 2232	2200 1012	2220 0112	3212 0111
Hu	0000 3443	2112 4433	2102 2221	1111 3332	2223 4643	2001 3332	2211 3543	1201 2321
Wa	1110 2222	1111 2123	3112 1112	2121 1223	2233 3421	3211 2123	3321 1303	3312 1112
	9	10	11	12	13	14	15	16
Si	0111 1010	1114 4422	1013 3332	1104 4311	1042 3211	0100 0000	0002 1010	0021 1111
Ch	1000 0121	2112 2323	1113 3333	3104 3322	1131 2122	0100 0200	0001 1011	1010 1113
Tu	1111 0211	1023 3333	2113 2354	2103 3322	2232 2221	0100 0101	1001 1011	1000 1112
SJ	0012 2210	2013 3222	1113 2343	2001 3321	0122 2321	0001 2000	0001 2131	1002 0223
Ho	0100 1122	0123 2123	2102 2232	1103 2212	0120 2210	1100 0000	1101 0001	1000 0122
Hu	1001 2431	1122 5543	2113 5543	1002 3542	1111 4322	0010 2200	0002 2221	0001 2322
Wa	2111 1111	1122 2222	3223 2443	2113 3422	2121 3211	1121 1001	1121 1111	2021 1114
	17	18	19	20	21	22	23	24
Si	1243 3100	1130 1110	1245 7541	0111 1000	0133 3301	2344 3220	0133 4100	1310 1100
Ch	2123 1111	2121 1121	2334 5331	2210 0000	1124 3010	3333 3221	0333 3111	2310 1001
Tu	3233 3212	0231 2133	3343 5323	3211 0111	1134 3010	2343 3322	1433 3013	[illegible] 1111
SJ	3133 1331	[illegible]	3333 4331	2100 1100	[illegible]	[illegible]	[illegible]	[illegible]
Ho	2132 [illegible]	2111 1122	3343 4221	[illegible]	[illegible]	[illegible]	[illegible]	1010 0111
Hu	2112 2321	2121 3331	3324 4532	0101 1010	1124 5423	[illegible] 3422	[illegible] 3313	1111 3321
Wa	3233 3111	2121 [illegible]	3244 4421	[illegible]	[illegible]	[illegible] 2211	[illegible]	1321 1211
	25	26	27	28	29	30	31	
Si	0012 0044	1124 4421	0342 1122	2233 3101	1032 3210	0100 0000	0022 3220	
Ch	1111 0035	1224 2312	2432 2123	3132 2100	2130 2100	0200 0000	1110 0110	
Tu	1121 1134	[illegible]	3443 1133	[illegible]	[illegible]	1110 0111	1121 1221	
SJ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1112 3211	
Ho	1110 0034	1114 2310	[illegible]	1131 1101	1131 1010	[illegible]	1101 1010	
Hu	0111 3355	1113 3521	1222 3432	2101 3321	1111 3221	[illegible]	0101 2320	
Wa	1111 1135	2233 3321	1232 2343	2131 3111	1331 2213	1111 1111	0122 1111	

' Interpolated

Table 3--Weighted average of reduced three-hour-range indices, October to December 1946

Day	October 1946 Values K_A								Sum	November 1946 Values K_A								Sum	December 1946 Values K_A								Sum
1	3	2	3	3	3	3	3	1	23	3	3	3	5	3	3	2	3	25	0	0	0	0	1	3	3	2	9
2	1	3	3	1	3	3	1	0	17	1	1	3	2	1	1	1	1	13	2	1	1	1	3	2	2	3	14
3	2	3	2	1	2	3	1	0	15	1	0	2	0	1	1	0	1	7	3	1	1	2	1	0	0	0	10
4	2	2	2	2	2	3	2	1	17	1	0	0	2	2	1	2	3	11	1	1	2	0	1	2	2	2	13
5	1	2	2	2	4	4	3	1	19	1	2	2	4	3	3	3	2	21	2	2	2	2	2	3	2	2	18
6	2	2	3	3	2	2	3	3	22	3	3	3	4	4	4	2	3	27	3	2	1	1	1	1	2	2	15
7	2	1	3	3	3	3	2	1	20	3	3	0	0	1	2	1	0	11	3	3	2	1	1	3	2	2	18
8	1	2	0	0	0	2	2	2	12	0	0	0	1	1	1	1	2	9	2	3	1	2	1	1	1	0	12
9	3	4	4	4	3	3	3	4	30	2	1	1	2	2	2	2	3	16	1	1	0	1	1	1	1	1	8
10	2	1	1	2	2	2	3	2	16	3	1	0	1	1	2	3	3	16	1	1	1	2	2	3	2	2	17
11	2	2	1	1	3	2	2	1	16	4	3	3	3	1	2	2	3	23	2	1	1	3	2	3	3	3	19
12	3	3	2	0	0	1	1	2	14	3	4	3	2	1	3	2	1	20	2	1	0	3	2	3	2	2	16
13	2	1	1	1	0	0	0	1	7	1	1	1	1	1	1	2	2	11	1	1	2	1	2	2	1	1	13
14	1	0	2	1	1	2	1	1	11	0	0	0	1	1	1	1	1	7	0	1	0	0	0	0	0	0	4
15	0	0	1	2	1	1	1	2	11	0	0	4	3	2	2	3	3	18	0	0	0	1	1	0	1	1	6
16	1	1	2	2	2	1	1	2	14	3	3	3	2	2	2	2	2	20	1	0	1	1	1	1	1	3	10
17	0	1	2	0	0	0	1	1	7	1	2	0	0	1	1	1	2	10	2	2	2	2	2	1	1	1	15
18	1	1	0	0	0	0	1	1	5	1	1	1	2	1	1	0	1	10	2	1	2	1	1	1	2	1	14
19	0	1	0	1	1	2	2	3	12	2	2	3	3	2	2	2	4	22	3	3	3	4	4	3	3	1	26
20	3	3	3	3	3	3	4	3	26	2	2	1	2	3	3	3	3	21	2	2	0	0	0	0	0	0	7
21	2	1	0	1	1	2	2	2	13	4	3	3	4	4	2	2	3	27	1	1	2	4	2	2	0	2	16
22	2	1	2	2	2	1	1	0	13	3	4	3	2	1	3	1	2	19	2	3	3	3	2	2	1	1	18
23	1	2	2	2	2	1	0	1	13	2	2	2	2	2	1	0	1	14	0	3	3	2	2	2	0	1	15
24	1	0	0	1	3	2	1	1	11	0	4	3	4	6	3	2	2	26	1	2	1	0	1	1	0	0	9
25	2	1	2	2	1	2	1	1	14	2	3	3	3	3	4	3	3	25	0	1	1	1	0	0	3	5	13
26	2	3	3	3	3	3	2	4	25	3	3	1	1	1	2	1	0	12	1	1	2	3	2	3	1	1	16
27	5	4	5	5	4	4	2	3	34	0	0	0	0	0	0	0	0	2	1	3	3	1	1	1	2	3	17
28	2	2	3	2	2	2	1	1	15	0	0	2	1	1	0	1	1	7	2	1	2	1	2	1	0	1	13
29	2	1	1	3	1	1	1	1	14	1	0	0	0	0	0	0	0	2	2	1	2	1	2	2	1	1	13
30	1	1	2	1	0	1	0	0	8	0	0	0	0	2	1	0	0	4	0	1	0	0	0	1	0	0	5
31	0	0	3	2	4	4	2	2	19										0	1	1	1	1	1	1	0	9

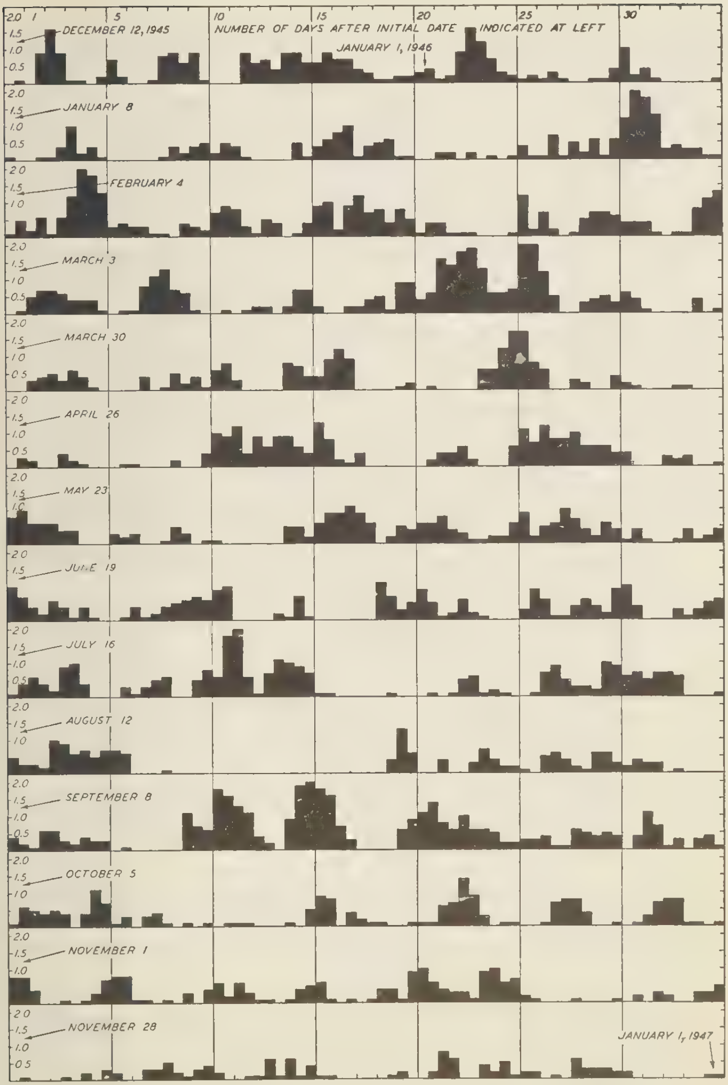


FIG. 1—AMERICAN CHARACTER-FIGURE, C_A, GREENWICH HALF-DAYS IN 27-DAY SEQUENCES, DECEMBER 12, 1945 TO JANUARY 1, 1947

increased magnetic activity and greater regularity. Recurrences of disturbed periods of four to six days for several solar rotations are apparent, as also quiet-day recurrences.

Daily indices B, given to half-units, and derived from the weighted indices in the manner outlined on pages 441-442 of the December 1939

issue of this Journal, are given in Table 5 for the year 1946. Eight indices are given for each date, for 24-hour periods starting every three hours of the Greenwich day.

The first B-index entered against each date refers to the *ordinary Greenwich day*, starting at Greenwich mean midnight; the second, third, ..., eighth indices refer to the 24 hours beginning at 03^h, 06^h,..., 21^h GMT for the same Greenwich date. If indices for *local days* (starting at local midnight) are wanted, the first column of figures should be used for stations between 22°.5 east and 22°.5 west longitudes, the second column for sta-

Table 4—*Mean magnetic character-figure assignments of individual observatories for half-days, 1946*

Observatory	Inter-val GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
	h h													
Cheltenham	00-12	0.34	0.45	0.66	0.37	0.55	0.50	0.53	0.24	0.58	0.39	0.42	0.18	0.43
	12-24	0.26	0.50	0.47	0.38	0.42	0.50	0.48	0.21	0.52	0.24	0.25	0.11	0.36
	00-24	0.30	0.47	0.56	0.38	0.48	0.50	0.51	0.23	0.55	0.31	0.33	0.15	0.40
Honolulu...	00-12	0.16	0.34	0.55	0.28	0.42	0.35	0.37	0.19	0.50	0.23	0.28	0.08	0.31
	12-24	0.13	0.25	0.40	0.22	0.24	0.23	0.32	0.10	0.45	0.18	0.20	0.10	0.24
	00-24	0.15	0.29	0.48	0.25	0.33	0.29	0.35	0.14	0.48	0.20	0.24	0.09	0.27
Huancayo..	00-12	0.11	0.25	0.44	0.27	0.32	0 30	0.34	0.15	0.42	0.18	0.22	0.08	0.26
	12-24	0.45	0.71	0.69	0.43	0.40	0.47	0.42	0.32	0.70	0.58	0.67	0.48	0.53
	00-24	0.28	0.48	0.56	0.35	0.36	0.38	0.38	0.23	0.56	0.38	0.44	0.28	0.39
San Juan...	00-12	0.19	0.29	0.58	0.30	0.42	0.38	0.37	0.20	0.40	0.15	0.22	0.11	0.30
	12-24	0.26	0.39	0.50	0.28	0.32	0.32	0.29	0.24	0.42	0.16	0.20	0.15	0.29
	00-24	0.23	0.34	0.54	0.29	0.37	0.35	0.33	0.22	0.41	0.15	0.21	0.13	0.30
Sitka......	00-12	0.27	0.38	0.48	0.33	0.32	0.35	0.35	0.19	0.50	0.21	0.20	0.18	0.31
	12-24	0.19	0.34	0.42	0.22	0.16	0.23	0.32	0.13	0.40	0.16	0.15	0.13	0.24
	00-24	0.23	0.36	0.45	0.28	0.24	0.29	0.34	0.16	0.45	0.19	0.18	0.15	0.28
Tucson.....	00-12	0.34	0.52	0.60	0.33	0.41	0.48	0.52	0.24	0.63	0.29	0.32	0.19	0.41
	12-24	0.26	0.55	0.45	0.28	0.29	0.45	0.53	0.23	0.58	0.24	0.23	0.13	0.35
	00-24	0.30	0.54	0.52	0.31	0.35	0.47	0.52	0.23	0.61	0.27	0.28	0.16	0.38
Watheroo...	00-12	0.50	0.62	0.71	0.47	0.58	0.38	0.45	0.24	0.60	0.37	0.37	0.24	0.46
	12-24	0.53	0.59	0.71	0.43	0.47	0.42	0.45	0.26	0.73	0.48	0.47	0.31	0.49
	00-24	0.52	0.61	0.71	0.45	0.52	0.40	0.45	0.25	0.67	0.43	0.42	0.27	0.48
Means.....	00-12	0.27	0.41	0.57	0.34	0.43	0.39	0.42	0.21	0.52	0.26	0.29	0.15	0.36
	12-24	0.30	0.48	0.52	0.32	0.33	0.37	0.40	0.21	0.54	0.29	0.31	0.20	0.36
	00-24	0.29	0.44	0.55	0.33	0.38	0.38	0.41	0.21	0.53	0.28	0.30	0.18	0.36

Table 5--Daily indices, B, from weighted reduced-indices, 1946

January 1946								February 1946								March 1946								April 1946							
2^x	2^x	2^x	2^x	2	2	2	2	1^x	1^x	2	2^x	2^x	2^x	2	2	3^x	3^x	3	3	2^x	3	3	2^x	2^x	2^x	2^x	2^x	2^x	3	3	3
1^x	1^x	1^x	2	4	4^x	5	5	2	2	1^x	1	1	1^x	2	2	2^x	2^x	2	2	1^x	1^x	1^x	1^x	3	3	2^x	2^x	2	2	2	1^x
5^x	5^x	5^x	6	5^x	5	4^x	4^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2	1	1	1^x	1^x	2	2^x	2^x	2^x	1^x	1^x	2	1^x	1^x	1^x	1^x	1^x
4^x	4	3^x	3	3	3	2^x	2^x	2^x	2^x	2^x	2^x	2	2	2^x	2^x	3	3	3	3	3	3	3^x	3	1^x	1	1	1	1	1^x	1^x	2
2	2	2	2	2	2	2	2^x	2^x	2^x	2	2	2	2^x	2	2^x	3	3	3	3	3	3	2^x	2^x	2	2	2	2	2	2	2	1^x
2	2	2	1^x	1^x	1^x	1^x	1^x	2	2^x	2^x	2^x	4^x	5^x	6	6	2^x	2^x	2^x	2	2^x	2	2	2	1^x	2	2	2	2^x	2^x	2^x	2^x
1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	6^x	7	7	7	7	7	6^x	6^x	2	2	2	2	1^x	1	1	1^x	2^x	2^x	2	2	2^x	2	2	2
1^x	1^x	1	1	1	1	1	1	6	5^x	4^x	4	3^x	3	2^x	2^x	1^x	1^x	1^x	1^x	1^x	1^x	2^x	2^x	2	2^x	2^x	2^x	2^x	3	3^x	3^x
1	1	1	1	1	1^x	1^x	1^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	3	3^x	3^x	4	4	4	4	3^x	3^x	3^x	3^x	3	3	2^x	2^x
1^x	2	2^x	3	3^x	3^x	3^x	3^x	2^x	2^x	2^x	2	2	2	2	2	4^x	4^x	4^x	4	4	4	4	3^x	2	1^x	1^x	1^x	1	1	1	1
3^x	3^x	3	2^x	2^x	2^x	2^x	2^x	1^x	1^x	1^x	1^x	1^x	1	1^x	1^x	3^x	3	2^x	2^x	2^x	2^x	2	2	1	1	1	1	1^x	1^x	1^x	2
2	2	1^x	1^x	1	1	1	1	2	2	2	2	2^x	2^x	2^x	2^x	1	1	1	1	1	1	1	1^x	2^x	3	3	3	3	3^x	3^x	3^x
1	1	1	1	1	1	1	1	2	2	2^x	3	3	3	3	3^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	3	3	3	2^x	2^x	3	3	3
1	1	1	1	1	1	1	1	3^x	4	4	4	3^x	4	3^x	3^x	1^x	1^x	1^x	1^x	2	2	2^x	2	3	3^x	3^x	4	4^x	4^x	4^x	4^x
1	1^x	2	2	2	2	2	2	3	3	2^x	2	1^x	1^x	1^x	2	2	2	2	2	1^x	1	1	1	4^x	4^x	4^x	4	3^x	2^x	2	1^x
2	2	2	2	2^x	2	2^x	2^x	2	2^x	2^x	2^x	2^x	2^x	2^x	2	1^x	2	2^x	2^x	2^x	3	3	3	2	2	1^x	2	2	2	2	1^x
2^x	2^x	2^x	2	2	2	2^x	2^x	2	1^x	1	1	1	1	1^x	1^x	3^x	3	3	3	3	2^x	2^x	2	1^x	1^x	1^x	1^x	1^x	1^x	1^x	2
2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	1^x	2	2^x	3	3	3	3^x	3^x	2	2	2	2	1^x	1^x	1^x	1^x	2	1^x	1^x	1^x	1^x	1^x	1^x	1
2	2	2	1^x	1^x	1^x	1	1	4	3^x	3^x	3	3	3	3	2^x	2	2	2	2	2^x	2^x	2^x	2^x	1^x	1^x	1^x	1	1	1^x	1	1
1	0^x	0^x	0^x	0^x	0^x	0^x	0^x	3	3^x	3^x	4	4^x	4^x	4^x	4^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	1	1	1	1	1	1	1	1
1	1	2	2^x	2^x	2^x	2^x	2^x	4^x	4	4	4	3^x	3^x	3	3	2^x	2	2	2^x	3	3	3	3	1	1	1	2	2^x	2^x	3	3
2^x	2^x	2^x	2	2^x	2	2^x	2^x	3	3	3	3	3	3	3	3	3^x	3^x	3^x	3	3	2^x	3	3	3	3^x	3^x	3^x	4	4^x	5	5
2^x	3	3	3	3	3^x	3^x	3^x	3	3	2^x	2^x	2	2	2	2	3	4	4^x	4^x	5	5^x	5^x	5^x	5^x	6	6	6	6	6	6	6
3^x	3^x	3^x	3	3	2^x	2^x	2	2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	5^x	5^x	5^x	5^x	6	6	6	6^x	5^x	5	4^x	4	3^x	3^x	3	2^x
2	2	2^x	2^x	3	2^x	3	3	2^x	2	2	2	1^x	1^x	1^x	1^x	6^x	6^x	6^x	6^x	6	5^x	5	4^x	2^x	1^x	1	1	1	1	1	1^x
3	3	2^x	2^x	2	2	2	1^x	1^x	1^x	1^x	1^x	1	1	1	0^x	4	4	3^x	3^x	3	3	3	3	2	2^x	2^x	2^x	2	2	2	2
1^x	1^x	1	1	1	1	1	1	0^x	0^x	0^x	0^x	0^x	1	0^x	1	3^x	3^x	3^x	5	6^x	7^x	8	8	1^x	0^x	0^x	0^x	1	1	1^x	2
1	1	1^x	1^x	1^x	2	2	2	1	2	2^x	3	3^x	3^x	3^x	3^x	8	8	8	8	7	6	5	4^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2
2	2	2	2	2	2	2	2									3^x	3	2^x	2^x	2	1^x	1^x	1^x	2	2	2	1^x	1^x	1^x	1^x	1^x
2	1^x	1^x	1^x	1^x	1^x	2	1^x									1^x	1^x	1^x	2	2	2	2	2	1	1	1	1^x	1^x	1^x	1^x	1^x
2	2	2	1^x	1^x	1^x	1^x	1^x									2^x	2^x	2^x	3	2^x	2^x	2^x	3								

May 1946								June 1946								July 1946								August 1946							
2	2	2	2	2	2	2	2	1^x	2	1^x	1^x	1^x	1^x	1^x	1^x	0^x	0^x	1	1^x	1^x	1^x	1^x	2	1^x	1	1	1	1	1	1	1
1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1	1	1	1	1	0^x	0^x	2	2	2	2^x	2^x	2^x	2^x	2^x	1	1	1	1	1	1	1	1
1^x	1^x	1^x	2	2	2	2	2	0^x	0^x	0^x	1	1	1^x	1^x	1^x	2^x	2^x	2^x	2	1^x	1^x	1^x	1^x	1	1	1	1	1	1	1	1
2	2	2	1^x	1^x	1	1	1	1^x	1^x	1^x	1	1	0^x	0^x	2	1	1	1	1	1	0^x	0^x	0^x	1	1	1	1	1^x	1^x	1^x	1^x
1^x	2	2^x	3	3^x	3^x	3^x	3^x	2^x	2^x	2^x	2^x	3	3	3	2^x	0^x	1	1	1	1	1	1	1	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
4	4	4	4	4	4	4	4	2^x	2^x	2	2	2^x	3	3^x	4	1^x	1^x	2^x	2^x	3	3	3^x	3^x	1^x	2	2	2	2^x	2^x	3	3
3^x	3^x	3	3^x	3^x	3^x	3^x	3^x	4	4	4	4	4	3^x	3^x	3^x	3^x	4	3^x	3^x	3	3	3	3	3	3	3	3	3	2^x	2^x	2
3^x	3^x	3^x	3^x	3^x	3^x	3^x	3^x	3^x	3^x	4	4	3^x	3^x	3^x	3^x	2^x	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1^x
4	3^x	3^x	3^x	3^x	3^x	3	3	3	3	2^x	2^x	2^x	2	2	2	3	3	2^x	2^x	2^x	2	2^x	2	1^x	1	1	1	1	1	1	1
3	3	3	4	4	4	4	4^x	2	2	2	2^x	2^x	2^x	2^x	2^x	2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	1	1^x	2	2^x	2^x	3	3	3
4	4	4	3	3	2^x	2	2	2^x	2^x	2^x	2^x	2^x	2^x	3	3	2^x	2	2	2	2	2	2	1^x	3^x	3^x	3^x	3	3	2^x	2^x	2^x
2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	1^x	1^x	1	1	1	1	1	1	2^x	2	2^x	2	2	2	2	2
2	1^x	1^x	1^x	1	1^x	1^x	1^x	2^x	2^x	2^x	2^x	2	2	2	2	1	1	1^x	1^x	2	2^x	3	3	2	2	2	2^x	3	3^x	3^x	3^x
1	1	1	1	1	1	1^x	1^x	2	2	2	1^x	1^x	2	2	2	3	3	3^x	3^x	3^x	3	2^x	2^x	3^x	4	4	3^x	3^x	3	3	3
1^x	1^x	1^x	1^x	1^x	2	2	2	1^x	2	2	1^x	2	2	2	2^x	2^x	2^x	1^x	1^x	2	2	2	2^x	3	3	3	3	2^x	2^x	3^x	3
2	2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	3	3^x	3^x	3^x	3	3	3	2^x	2^x	3	3	3	3	3	3	3	3	3	3	3^x	3^x	3^x	3^x
2^x	2^x	2^x	2^x	3	2^x	2^x	2^x	3	2^x	2^x	2	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2	2^x	2^x	3	3	3	3	3	2^x	2^x	2	1^x	1^x
2^x	2^x	2	2	1^x	1^x	1	0^x	3	3	3	3^x	3^x	3^x	3^x	3^x	3^x	3^x	3^x	4	4	4	3^x	3^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
0^x	0^x	0^x	0^x	0^x	0^x	1	1^x	3^x	3^x	3^x	3	3	2^x	2^x	2^x	3^x	3	3	2^x	2	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
2^x	3	3	3^x	3^x	4	4	4	2	2	2	2^x	2^x	2^x	2^x	2^x	1^x	1^x	1^x	1^x	1^x	2	2	2	1	1	1	1	1	1	0^x	0^x
3^x	3^x	4	4	4	4	4	4	2^x	3	2^x	2^x	2	2^x	2^x	2^x	2	2	2^x	2^x	2^x	2^x	2^x	2^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
4	4^x	4	3^x	3^x	3^x	3^x	3^x	2	2	2	2	2	2	2	1^x	2^x	2^x	2^x	2^x	3	3	3	3	0^x	0^x	0	0	0	0	0	0
4	3^x	3^x	3^x	3^x	3^x	3^x	3	1^x	1	1	1	0^x	0^x	0^x	1	3	3	2^x	2^x	2	2	2	1^x	0	0^x	0^x	1	1	1^x	1^x	1^x
3	3	3	3	3	3	3	2^x	1	1^x	1^x	2	2	2	2	2	1^x	1^x	1^x	2	2	2	2^x	2^x	1^x	2	2	1^x	1^x	1^x	1^x	1^x
2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4^x	1^x	1	1	0^x	0^x	0^x	0^x	0^x
2	2	2	2	1^x	1	1	1	2^x	2^x	2	2^x	2^x	2^x	2^x	2^x	5	6	6^x	7	7	7	7	6^x	0^x	0^x	1	1	1	1^x	1^x	1
1	1^x	1^x	1^x	1^x	2	2	2	3	3	3	3	3	3	3	3	6^x	5^x	4^x	3	2^x	2^x	2^x	2^x	1^x	1^x	1^x	1	1	1	1	1
2	2	2	2	2	2	2	2	3	3	3	3	3	3	3^x	3^x	2^x	3	3^x	3^x	4	4	4	4^x	1	1	1	1	1	1	0^x	0^x
1^x	1^x	1^x	1^x	1	1^x	1^x	1^x	3^x	3^x	3^x	3^x	3	3	2^x	2	4^x	4^x	4	4	4	4	4	3^x	0^x	0^x	0^x	0	0	0	0	0^x
1^x	2	2	2^x	2^x	2^x	2^x	2^x	1^x	1^x	1	1	1	1	1	0^x	3^x	3^x	3	3	2^x	2	2	1^x	1^x	2^x	3	3^x	4	4	4	4
2^x	2^x	2^x	2	2	1^x	1^x	1^x									1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	4	3^x	3	2^x	2^x	2	1^x	1

Table 5--Daily indices, B, from weighted reduced-indices, 1946--concluded

Day	September 1946								October 1946								November 1946								December 1946						
1	1	1^x	1^x	2	2	2	2	2	3	3	3	3	2^x	3	2^x	2^x	3^x	3^x	3^x	3^x	3	2^x	2^x	2^x	1^x	1^x	1^x	1^x	2	2	2
2	2	2	2	1^x	1^x	1^x	1^x	1^x	2^x	2^x	2^x	2^x	2^x	2	2^x	2^x	2	2	2	1^x	1	1	1	1	2	2	2	2	2	2	2
3	1^x	1^x	2	2	2^x	3	3	3	2^x	2^x	2	2	2^x	2^x	2	2^x	1	1	1	0^x	1	1	1^x	1^x	1^x	1	1	1^x	1	1	1^x
4	3	3	3	2^x	2^x	2^x	2^x	2^x	2^x	2	2	2	2	2^x	2^x	3	1^x	1^x	1^x	2	2^x	2^x	2^x	3	2	2	2	2	2	2^x	2^x
5	2^x	2^x	2^x	2^x	2	2	1^x	1^x	3	3	3	3	3	3	2^x	2^x	3	3	3	3	3^x	3^x	3^x	3^x	2^x	2^x	2^x	2^x	2^x	2^x	2
6	1^x	1	0^x	1^x	2	2^x	2^x	3	3	3	2^x	2^x	3	3	3	3	3^x	3^x	3^x	3^x	3	2^x	2^x	2	2	2	2^x	2^x	2^x	2^x	2^x
7	3	3	3	3	2^x	2^x	2^x	2	2^x	2^x	2^x	2^x	2	1^x	1^x	1^x	2	1^x	1	1	1	1	1	1	2^x	2^x	2^x	2	2^x	2^x	2
8	2^x	2^x	2^x	2^x	2	2^x	2^x	2^x	1^x	2	2^x	3	3^x	3^x	3^x	3^x	1^x	1^x	1^x	1^x	2	2	2	2	2	1^x	1	1	1	1	1
9	2^x	2^x	2^x	3	3	3	3	2^x	4	3^x	3^x	3	2^x	2^x	2^x	2^x	2	2^x	2^x	2	2	2	2	2^x	1	1	1	1^x	1^x	1^x	2
10	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2	2	2^x	2^x	2	2^x	2^x	2^x	2^x	2^x	3	3	3	3	3	3	2	2^x	2^x	2^x	2^x	2^x	2^x
11	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2^x	2	2^x	2^x	2^x	2^x	2	2	2	3	3	3	3	3	3	3	3	2^x	2^x	2^x	2^x	2^x	2^x	2^x
12	2^x	2^x	2^x	2^x	2	2	2	2	2	2	1^x	1^x	1^x	1^x	1^x	1	3	2^x	2	2	2	2	1^x	1^x	2^x	2	2	2^x	2	2	2
13	2	2	1^x	1^x	1^x	1^x	1^x	1^x	1	1	1	1	1	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1	1^x	1^x	1^x	1^x	1^x	1	1
14	1^x	1^x	1^x	1^x	1^x	1^x	2	2	1^x	1^x	1^x	1	1^x	1^x	1^x	1^x	1	1	1	2	2	2^x	2^x	2^x	0^x	0^x	0^x	0^x	0^x	0^x	0^x
15	1^x	1^x	1^x	1^x	1^x	2	2^x	3	1^x	1^x	1^x	2	2	2	2	2	2^x	3	3	3	3	3	3	3	1	1	1	1	1	1	1
16	3^x	3^x	4	4	4	4	3^x	3	2	2	2	2	1^x	1^x	1^x	1^x	2^x	2^x	2	2	1^x	1^x	1^x	1^x	1^x	1^x	2	2	2	2^x	2^x
17	3	4	4	5	5	5^x	6	6	1	1	1	0^x	1	1	0^x	0^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x	2	2	2	2	1^x	1^x	1^x
18	6	6	6	5^x	5^x	5	5	4^x	0^x	0^x	0^x	0^x	0^x	1	1	1^x	1^x	1^x	1^x	2	2^x	2^x	2^x	2^x	2	2	2	2^x	3	3	3^x
19	4^x	4^x	4	4	3^x	3	2^x	2^x	2	2	2^x	3	3	3	3	3^x	3	3	3	3	2^x	3	3	3	3^x	3^x	3	3	2^x	2	1^x
20	2	2	2	1^x	1^x	2	2^x	3	3^x	3	3	3	2^x	2^x	2^x	2	2^x	3	3	3	3^x	3^x	3^x	3^x	1	1	0^x	1	2	2	2^x
21	3	3	4	4^x	6	7	7^x	7^x	2	2	2	2	2	2^x	2	2	3^x	3^x	3^x	3^x	3	3	3	3	2^x	2^x	2^x	2^x	2^x	2^x	2^x
22	7^x	7^x	7^x	7^x	7	6^x	6	6	2	1^x	2	2	2	2	2	1^x	2^x	2^x	2^x	2	2	2^x	2	2	2^x	2^x	2^x	2^x	2	2	2
23	6	6	5^x	5	5	4^x	4	3^x	2	2	1^x	1^x	1	1^x	1^x	1^x	2	1^x	2^x	2^x	3	3^x	3^x	4	2	2^x	2	2	1^x	1^x	1^x
24	3	2^x	2^x	2	1^x	1	1	0^x	1^x	1^x	2	2	2	2	2	2	4	4	3^x	3^x	3^x	3	3	3	1	1	1	1	1	1	0^x
25	1	0^x	1	1	1	1^x	1^x	1^x	2	2	2	2^x	2^x	2^x	2^x	3	3	3^x	3^x	3	3	2^x	2^x	2	2^x	2^x	2^x	2^x	3	3	3
26	1^x	2	2	2^x	2^x	3	3	3^x	3	3^x	4	4	4^x	4^x	4^x	4^x	2	1^x	1	1	1	0^x	0^x	0^x	2^x	2^x	2^x	2^x	2^x	2	2
27	3^x	4	4	4^x	4^x	5	5	5	4^x	4	4	3^x	3^x	3	2^x	2^x	0^x	0^x	0^x	0^x	0^x	1	1	1	2^x	2^x	2^x	2	2	2	2
28	5	5	5	5	4^x	4^x	4	3^x	2	2	2	1^x	2	2	2	2	1	1	1	1	0^x	0^x	0^x	0^x	1^x	1^x	1^x	1^x	1^x	1^x	1^x
29	3^x	3	3^x	3^x	3^x	3^x	3^x	3^x	2	1^x	1^x	2	1^x	1^x	1^x	1	0^x	0^x	0	0	0^x	0^x	0^x	0^x	1^x	1^x	1^x	1^x	1^x	1	1
30	3^x	3^x	3^x	3^x	3	3	3	3	1	1	1	1^x	1^x	2	2^x	3	0^x	0^x	0^x	0^x	0^x	0^x	1	1	0^x	0^x	0^x	1	1	1	1
31									3	3	3^x	3^x	3^x	3^x	3^x	3^x									1	1	1	1	1^x	1^x	1^x

tions between 22°.5 west and 67°.5 west, the third column for stations between 67°.5 west and 112°.5 west, and the fourth column for stations between 112°.5 west and 157°.5 west; the fifth column should be used, with the same local date as the Greenwich date, for stations between 157°.5 west and the date-line, and, with the local date following the Greenwich date, for stations between the date-line and 157°.5 east. Likewise, the sixth column refers to local days for stations between 157°.5 east and 112°.5 east, the seventh column to stations between 112°.5 east and 67°.5 east, and the eighth column to stations between 67°.5 east and 22°.5 east; but the index entered in the Table against *January 1*, refers, in the sixth, seventh, and eighth columns, to the local day with the date *January 2*.

The weighted mean indices, K_A, for the period December 12, 1945, to January 3, 1947, are shown graphically in Figure 2. They are arranged in "solar rotations" (not Carrington's rotation-interval of 27.275 days used in solar physics, but 27.0 days introduced by Bartels for the study of solar and terrestrial relationships), the first one being for solar-rotation period No. 1541 which began on December 12, 1945. Disturbed periods where the mean index was greater than 5 occurred on 46 days during 1946, as follows:

January 3, 4, and 11
February 7, 8, 14, 20, and 21

March 1, 10, 22, 23, 24, 25, 26, 28, and 29
April 15, 23, and 24

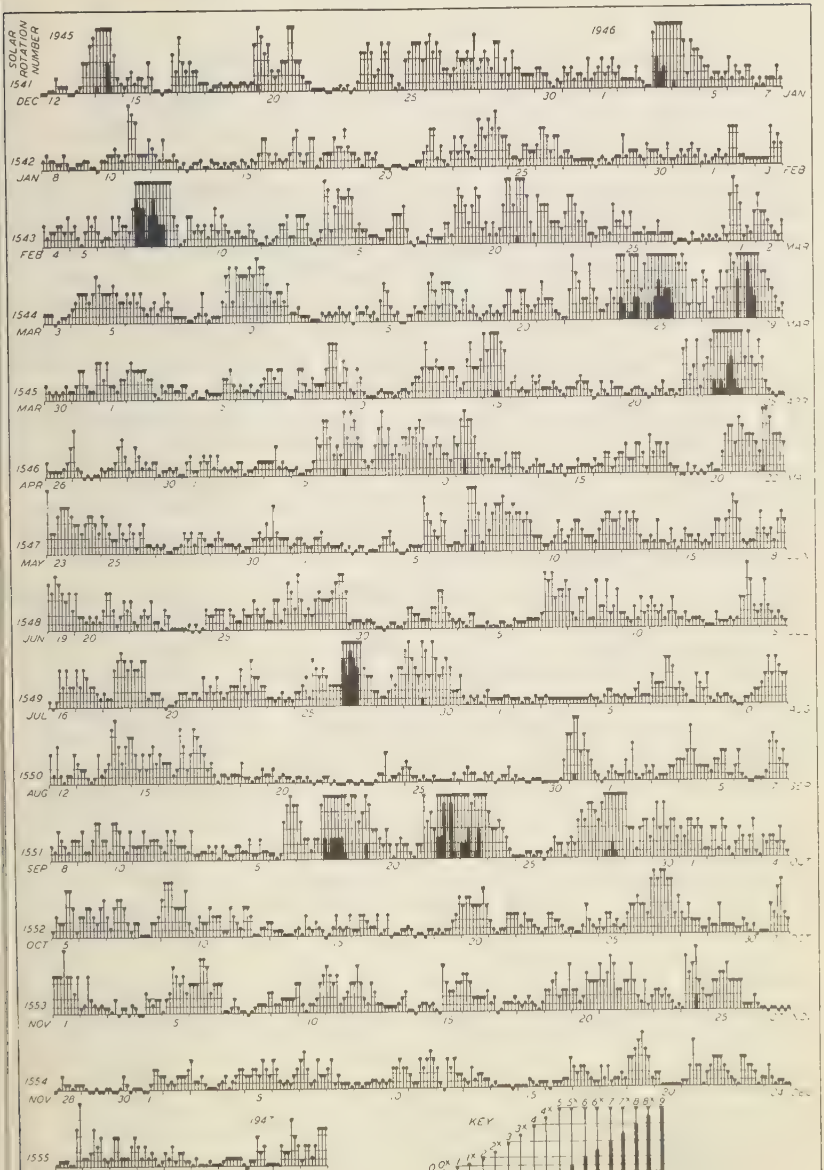


FIG. 2—WEIGHTED AVERAGE, K_A, OF REDUCED INDICES, K_r, FROM SITKA, CHELTENHAM, TUCSON, SAN JUAN, HONOLULU, HUANCAYO, AND WATHEROO, DECEMBER 12, 1945 TO JANUARY 3, 1947

May 6, 7, 8, 11, 22, and 23
June 7
July 14, 26, 27, 29, and 30
August 14 and 31
September 16, 18, 19, 21, 22, 23, 28, and 29
October 27
November 1 and 24
December 25

The spring and autumnal months of March and September were the most disturbed. There were several disturbances of outstanding magnitude during the year. Strictly speaking there were twelve storm-days selected from seven magnetic storms. The first magnetic activity of note was that on January 3. The largest sunspot-group ever recorded at Mount Wilson Observatory (No. 7943, over-all length 192,000 miles, 2.0 days past the central meridian, with minimum distance of 34° from the center of the solar disk) was reported in connection with the disturbance of February 7-8. The storm of March 28 was one of the most severe in recent years and was accompanied by strong aurora—both Borealis and Australis. An unusual cosmic-ray increase (only three such occurrences in ten years—February 1, 1942, March 7, 1942, and July 25, 1946) on July 25 was connected in some way with the storm of July 26-27. The disturbance on September 22-23 was quite violent.

The weekly issuance of American half-day character-figures, C_A, and American three-hour-range indices K and means K_A (entitled "Report of Geomagnetic Activity") was discontinued at the end of 1946 by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. In place of these, beginning with 1947, weekly reports of K-indices of the Cheltenham Magnetic Observatory—the most representative station of those formerly reporting the American figures—have been issued by the United States Coast and Geodetic Survey. With the correlation-coefficient of Cheltenham so high, the prediction of average K_m from this one value of K appears quite safe.

Grateful acknowledgment is made at this time to the observers at the several stations upon whose faithful reporting this project depended, as also to those individuals who cooperated in the communication service. Theirs has been useful labor, worth preserving.

Note: The Department of Terrestrial Magnetism plans to continue for the present the compilation of *world-wide* magnetic characters C and three-hour-range indices K, as also the selection of international five quiet and disturbed days for each month.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., January 16, 1947

MEAN K-INDICES FROM THIRTY MAGNETIC OBSERVATORIES AND PRELIMINARY INTERNATIONAL CHARACTER-FIGURES, C, FOR 1945

By W. E. Scott

K-indices have been received at the Department of Terrestrial Magnetism from 32 magnetic observatories for the year 1945. The records are not complete from all, but the average number reporting was 30. Those contributing were in order of geomagnetic latitude: Godhavn; Ivigtut (through July 16, 1945); College; Lerwick; Dombås; Meanook; Sitka; Eskdalemuir; Rude Skov; Agincourt; Witteveen; Abinger; Srednikan; Yakutsk; Cheltenham; Zaimishche; Vyssokaya Dubrava; Moscow; Zuy; San Fernando; Tucson; Dusheti; Tashkent (Keles); San Juan; Honolulu; Huancayo; Apia; Pilar; Hermanus; Watheroo; Toolangi; and Amberley. [During 1946 the Alibag Magnetic Observatory, under the direction of Dr. S. K. Chakrabarty, initiated the three-hour-range indices, K.]

The mean indices, K_M, for successive three-hour periods of the Greenwich day are given in Table 1 for the year 1945. The agreement of K_M and K_A is consistent. K_A is the weighted mean index derived from the K-indices (normalized to represent world-wide conditions) received from seven American-operated observatories. The difference (K_M is always the larger, due probably to the great number of high-latitude stations represented) in monthly sums of K_M and K_A is nine per cent on the average.

The year was comparatively quiet since a K-index of 9 was observed only on four days—once January 29, once March 28, once April 1, and twice on December 14—in all instances at Sitka and on one occasion at College. Magnetic disturbances also occurred on January 15, March 12 and 15, April 11, August 28, September 18, October 24, November 9, and December 19. There was no perfectly calm three-hour interval, although there were seven Greenwich days when the value of K_M was 1.0 or less for all eight intervals, namely, January 24 and 25, February 21, August 20, November 26, December 1 and 4.

The mean K-indices by months for the Greenwich day are given in Table 2 and those by years for 1940 to 1945 in Table 3. The mean for the year 1945 is 1.91, the lowest value in this group of years. Reports were not received from Sodankylä, Slutsk, Chambon-la-Forêt, Zô-Sè, and Kuyper.

The utilization of K-indices for assistance in selecting the five international quiet and disturbed days is being continued. The selected days for the years 1944 and 1945 have appeared in previous issues of this Journal.

In *Geomagnetism* (Chapman and Bartels, II, Table E, pp. T14-T15, 1940) are given monthly and annual means of u for the period 1872-1938. For use in connection with the question of comparative geomagnetic

Table 1--Mean K-indices from thirty observatories, 1945

Day	January 1945									February 1945								
	Values K_M								Sum	Values K_M								Sum
1	1.6	1.5	1.7	2.6	2.1	1.9	3.3	2.6	17.3	1.6	1.8	1.0	0.7	0.8	1.1	1.3	0.8	9.1
2	2.8	2.0	2.5	1.6	2.2	2.6	2.0	1.7	17.4	0.6	0.9	1.5	2.5	3.3	3.1	2.6	2.1	16.6
3	1.3	1.2	1.5	3.1	2.0	2.2	2.9	1.2	15.4	2.1	2.3	0.8	1.7	1.4	2.0	0.6	0.9	11.8
4	0.6	0.7	0.6	1.5	1.8	2.5	3.5	3.2	14.4	0.8	2.1	1.4	0.8	0.8	1.7	1.2	1.5	10.3
5	2.0	1.5	1.5	1.7	1.5	1.1	1.3	0.7	11.3	2.2	4.1	3.8	3.0	2.1	2.1	3.0	1.8	22.1
6	2.2	1.2	1.4	2.6	1.7	0.8	1.3	1.7	12.9	3.1	1.8	2.1	3.4	1.7	1.5	2.2	1.6	17.4
7	1.2	1.9	1.1	2.2	1.8	1.0	1.1	1.7	12.0	0.8	0.9	1.9	2.4	1.2	1.8	2.5	1.4	12.9
8	1.1	0.6	1.2	1.0	2.0	1.3	0.9	1.1	9.2	2.7	2.5	2.6	2.9	3.0	3.0	1.3	3.2	21.2
9	1.1	0.9	1.2	1.5	1.6	2.8	1.8	4.5	15.4	3.2	2.2	2.8	3.1	3.1	2.4	2.4	2.2	21.4
10	4.5	3.5	3.9	3.4	3.5	2.6	2.3	0.5	24.2	1.6	1.9	2.0	3.4	0.8	0.8	1.7	1.6	13.8
11	0.8	0.5	0.6	0.5	0.5	0.8	1.0	1.2	5.9	2.2	2.7	2.4	2.0	1.4	2.9	1.4	0.9	15.9
12	0.8	0.7	1.3	0.6	2.1	1.8	2.3	1.8	11.4	1.4	2.5	2.4	0.7	0.9	1.5	0.8	1.4	11.6
13	2.7	2.8	2.2	1.6	0.8	0.9	0.4	0.4	11.8	0.7	0.7	0.8	1.6	1.7	0.8	0.4	0.5	7.2
14	1.0	1.0	1.0	1.2	1.4	1.2	1.1	1.6	9.5	0.4	0.7	0.7	1.3	1.4	1.8	2.4	3.0	11.7
15	2.4	3.6	3.6	3.8	4.4	5.3	5.2	2.7	31.0	3.5	3.0	2.6	4.1	4.1	2.5	3.7	3.2	26.7
16	3.3	2.5	2.5	2.7	1.5	1.7	2.0	2.9	19.1	3.6	2.3	2.5	2.9	3.5	3.1	4.0	2.7	24.6
17	2.9	2.9	1.8	3.4	2.6	2.5	3.5	1.5	21.1	1.5	1.5	1.8	2.1	2.0	2.8	3.5	2.4	17.6
18	0.8	0.6	0.7	0.8	1.1	1.6	2.3	2.6	10.5	2.2	1.5	1.5	0.9	2.2	1.7	0.9	2.0	12.9
19	2.2	2.3	1.5	1.7	1.8	2.9	3.1	1.7	17.2	1.9	1.3	1.1	1.3	1.6	1.0	0.9	1.5	10.6
20	1.7	2.3	2.2	2.5	2.9	1.7	1.3	1.3	15.9	1.1	0.6	1.0	1.0	1.5	2.2	0.7	1.2	9.3
21	1.8	1.9	1.3	1.0	1.5	1.3	1.2	1.9	11.9	1.0	0.9	0.9	0.5	0.5	0.6	1.0	0.8	6.2
22	1.2	0.7	0.8	0.8	1.1	1.3	1.0	1.5	8.4	0.9	0.8	1.5	2.3	2.5	1.7	1.7	2.2	13.6
23	0.9	1.3	0.9	0.8	1.0	0.5	1.2	1.0	7.6	1.1	0.8	0.6	2.8	2.8	2.2	1.7	1.9	13.9
24	0.4	0.4	0.7	0.7	0.6	0.4	0.7	0.5	4.4	1.4	1.9	1.4	1.6	1.4	1.7	2.7	2.2	14.3
25	0.5	0.6	0.7	0.6	0.5	0.7	0.7	0.5	4.8	3.6	2.7	2.0	2.4	1.6	1.5	3.4	2.1	19.3
26	0.6	0.8	1.3	2.3	2.6	3.1	2.8	1.9	15.4	1.2	2.3	1.4	1.4	2.2	4.7	4.7	3.6	21.5
27	1.8	1.2	1.1	1.5	2.3	1.3	1.7	1.2	12.1	2.6	2.1	2.9	1.9	3.3	2.8	4.3	2.5	22.4
28	2.3	1.2	0.8	1.0	1.7	2.6	4.1	4.4	18.1	2.2	2.3	1.0	0.9	1.5	2.2	2.6	0.9	13.6
29	4.9	5.3	3.8	3.0	3.2	4.5	4.6	3.6	32.9									
30	3.0	3.7	2.5	2.5	2.7	2.7	1.3	1.3	19.7									
31	0.8	1.2	0.8	1.1	1.0	1.0	0.7	1.5	8.1									

Day	March 1945									April 1945								
	Values K_M								Sum	Values K_M								Sum
1	1.6	1.5	1.3	2.5	1.6	1.5	0.9	0.8	11.7	1.9	3.6	5.3	5.4	5.0	4.4	3.5	3.1	32.2
2	0.8	0.7	0.8	1.4	1.9	3.0	1.4	1.2	11.2	3.9	3.0	2.5	1.6	2.4	2.7	2.2	1.0	19.3
3	2.9	2.5	2.9	3.0	2.2	2.3	2.0	0.6	18.4	1.5	2.2	1.6	0.7	1.1	0.6	0.7	0.6	9.0
4	1.3	1.0	1.1	1.6	1.6	1.2	1.5	2.0	11.3	0.8	0.9	1.0	0.8	3.5	2.8	1.2	0.9	11.9
5	2.0	1.7	1.4	1.7	2.8	4.3	4.7	4.1	22.7	0.6	0.6	0.9	3.0	1.9	3.0	4.7	3.7	18.4
6	2.4	1.5	2.6	2.5	3.0	3.7	3.4	2.7	21.8	2.2	2.2	3.8	4.2	3.2	4.2	2.7	3.0	25.5
7	2.1	1.9	2.7	3.1	1.8	2.6	1.8	1.4	17.4	3.3	3.2	3.8	1.7	1.9	1.6	1.7	4.1	21.3
8	2.4	3.6	3.0	4.3	4.0	4.1	1.0	0.8	23.2	3.5	2.7	3.1	3.3	2.9	2.5	1.0	1.3	20.3
9	0.8	1.1	0.9	1.6	1.0	2.0	2.4	2.8	12.6	1.4	1.6	1.1	0.4	0.6	1.0	0.7	0.3	7.1
10	1.8	1.0	1.3	1.2	1.3	1.1	0.9	2.7	11.3	1.1	1.1	0.6	1.1	2.6	1.1	0.6	1.4	9.6
11	4.4	3.7	3.3	4.4	4.5	4.6	3.8	1.8	30.5	1.0	1.5	3.7	4.9	5.5	3.8	2.6	3.9	26.9
12	2.7	2.9	2.9	5.0	5.1	5.0	5.2	5.2	34.0	4.0	3.8	3.3	3.0	2.3	3.5	4.0	3.8	27.7
13	3.1	1.5	2.2	3.0	2.9	1.3	1.0	1.0	16.0	3.0	2.7	3.0	2.9	2.3	1.7	2.4	2.7	20.7
14	0.9	2.1	2.1	2.3	2.2	2.5	2.8	3.3	18.2	3.9	3.3	2.4	2.9	3.0	3.4	3.2	3.2	25.3
15	5.6	4.0	4.4	3.2	4.1	5.5	4.2	5.0	36.0	2.7	2.9	3.2	3.5	2.8	1.9	1.5	1.7	20.2
16	3.9	2.8	2.6	3.6	3.5	4.1	3.0	3.4	26.9	1.5	1.0	2.1	1.2	1.4	1.7	1.7	1.5	12.1
17	2.8	1.8	1.9	1.5	1.3	2.0	2.2	2.8	16.3	1.6	1.4	1.0	1.1	0.8	1.2	0.9	0.7	8.7
18	1.9	2.1	1.8	2.2	2.7	2.4	2.4	2.5	18.0	1.0	1.4	1.8	1.6	0.9	0.5	0.7	1.6	9.5
19	2.1	1.5	0.8	1.2	1.8	1.3	1.1	1.4	11.2	2.2	1.9	2.5	2.8	3.1	1.7	2.6	2.7	19.3
20	2.5	1.1	1.7	1.8	1.6	1.5	5.0	4.6	19.8	3.0	2.7	3.2	3.5	3.5	2.4	2.0	0.7	21.0
21	2.0	1.7	1.7	2.2	1.6	2.1	3.6	1.2	16.1	1.3	0.5	0.7	0.8	1.5	1.0	1.0	2.3	9.1
22	1.2	1.6	1.1	1.1	0.5	0.4	0.5	0.5	6.9	1.9	0.8	1.0	1.5	1.4	2.2	3.5	2.7	15.0
23	0.9	1.2	1.0	1.6	1.1	0.8	1.0	0.7	8.3	1.7	1.6	2.1	2.9	2.9	3.6	2.4	2.8	20.0
24	0.7	1.2	1.9	2.9	2.2	2.8	2.5	2.3	16.5	3.3	2.9	3.5	2.8	2.0	2.5	3.3	2.3	22.6
25	2.1	1.1	0.7	1.4	2.4	3.3	2.1	3.6	16.6	2.5	2.2	2.3	2.3	1.7	1.5	0.9	1.2	14.6
26	4.5	3.9	4.8	4.9	4.7	4.9	4.4	4.4	36.5	0.4	0.6	0.7	0.9	1.8	1.5	0.7	0.6	7.2
27	3.1	2.5	2.3	3.5	3.5	3.3	4.1	3.7	26.0	1.5	1.6	0.4	0.5	0.5	0.6	0.9	1.0	7.0
28	3.2	3.1	4.8	6.2	5.9	3.1	2.6	2.2	31.1	0.6	0.7	0.5	0.8	1.2	1.3	0.6	1.4	7.1
29	1.3	2.5	3.5	3.3	3.2	2.5	1.6	2.6	20.5	0.9	1.0	0.7	1.6	2.2	2.2	2.1	1.6	12.3
30	0.8	2.0	1.5	1.0	1.5	1.6	0.8	0.6	9.8	1.3	1.7	2.7	3.7	1.7	3.1	2.8	2.1	19.1
31	1.0	0.6	0.6	0.4	0.7	1.2	1.2	2.1	7.8									

Table 1--Mean K-indices from thirty observatories, 1945--continued

Day	May 1945 Values K_M								Sum	June 1945 Values K_M								Sum
1	3.4	2.7	2.0	2.5	2.4	1.5	2.5	1.4	18.4	0.9	1.3	1.0	1.0	1.1	1.1	1.4	0.6	8.4
2	3.4	3.5	3.0	2.6	2.8	2.1	1.5	1.5	20.4	0.4	0.6	0.8	0.9	0.9	1.1	1.4	1.4	7.5
3	3.3	2.1	2.1	2.5	2.0	2.7	2.6	2.9	20.2	1.5	1.7	1.6	0.9	1.5	0.6	0.7	0.5	9.0
4	1.6	2.1	2.4	1.4	0.8	1.1	1.9	2.4	13.7	0.4	0.7	0.5	0.8	2.1	0.7	1.2	1.4	7.8
5	1.4	1.5	2.1	1.3	2.0	2.0	1.0	1.4	12.7	0.9	1.4	1.4	1.5	1.3	1.5	1.7	2.1	11.8
6	0.6	1.1	1.1	1.5	2.3	2.6	2.1	1.5	12.8	1.8	2.8	4.2	4.6	3.9	3.3	2.7	2.9	26.2
7	0.6	0.9	0.5	0.7	1.4	1.1	1.6	2.4	9.2	2.9	3.1	3.2	2.4	2.7	2.5	3.4	2.6	22.8
8	1.5	1.9	2.0	1.6	1.6	1.1	1.4	1.2	12.3	3.4	3.5	3.7	2.5	3.0	3.1	2.4	2.8	24.4
9	1.0	1.5	2.5	1.5	2.8	3.4	3.4	3.1	19.2	2.2	2.3	2.9	2.7	1.9	2.7	2.8	2.6	20.1
10	1.5	1.8	1.9	2.2	2.3	2.6	2.7	3.5	18.5	2.7	3.2	2.8	2.9	2.4	2.7	2.3	2.1	21.1
11	2.4	4.0	3.6	3.7	3.2	3.6	3.4	2.4	26.3	2.8	2.6	2.1	2.0	2.4	1.7	2.6	1.5	17.7
12	3.3	2.8	2.3	2.2	1.6	2.2	3.4	3.1	20.9	0.9	1.5	2.0	1.2	1.6	1.3	1.2	1.2	10.9
13	1.9	1.9	2.0	1.6	2.1	2.7	2.4	2.5	17.1	1.0	1.8	1.8	1.9	2.1	2.2	1.1	1.4	13.3
14	1.6	1.2	1.3	1.9	2.9	3.3	1.4	2.2	15.8	1.7	1.7	1.0	1.0	0.7	1.4	1.8	1.2	10.5
15	1.5	1.3	1.2	0.8	0.7	0.8	1.1	1.6	9.0	1.6	1.3	1.3	1.2	1.4	0.7	0.8	0.8	9.1
16	2.3	2.3	1.6	1.3	1.5	1.8	1.7	3.0	15.5	1.0	0.7	1.0	1.3	1.4	2.1	1.6	1.6	10.7
17	2.1	2.0	2.1	1.7	2.2	2.1	2.2	1.9	16.3	1.7	1.9	2.2	2.2	2.5	2.7	1.3	1.0	15.5
18	1.6	1.6	2.1	1.9	2.8	3.4	2.9	3.2	19.5	1.1	1.8	1.7	0.8	1.5	1.7	2.1	1.6	12.3
19	2.2	1.9	1.6	2.0	2.8	2.7	2.3	2.6	18.1	1.0	1.5	1.3	1.0	1.5	1.4	1.9	2.0	11.6
20	2.0	3.0	3.0	2.4	1.4	2.6	1.3	1.0	16.7	2.2	1.9	1.7	2.2	1.9	1.5	1.5	1.2	14.1
21	1.4	1.7	1.8	2.1	2.8	3.1	1.9	1.7	16.5	1.3	1.9	1.0	0.9	1.1	1.6	0.6	0.9	9.3
22	1.3	1.2	1.5	2.4	1.9	1.6	1.4	1.4	12.7	0.8	0.5	0.7	0.6	1.1	1.2	0.9	0.7	6.5
23	2.1	2.8	3.3	2.9	1.6	1.7	1.8	1.2	17.4	0.8	1.5	2.4	2.2	1.6	1.5	0.9	0.6	11.5
24	2.7	3.2	2.7	2.1	2.0	2.2	2.3	1.0	18.2	1.0	1.4	1.4	0.9	1.4	0.6	1.1	1.7	9.5
25	2.3	3.7	2.8	2.3	2.3	2.5	3.3	2.5	21.7	2.7	2.5	1.4	1.6	0.8	0.8	1.6	1.5	12.9
26	2.0	1.2	1.8	1.6	1.6	2.2	2.7	2.1	15.2	1.7	1.1	0.7	0.7	1.2	0.7	1.3	1.9	9.3
27	1.9	1.1	1.0	1.4	2.3	2.6	3.1	2.0	15.4	2.2	2.9	3.3	3.5	2.5	2.0	1.6	1.4	19.4
28	0.8	1.1	1.2	2.3	1.8	2.4	2.0	1.7	13.3	1.8	1.4	2.1	2.1	1.8	1.8	0.9	1.2	13.1
29	3.1	2.3	1.9	1.8	1.1	2.1	2.2	2.2	16.7	0.9	1.3	1.0	1.1	1.5	0.6	0.5	0.5	7.4
30	2.1	2.2	2.3	2.2	2.5	3.5	2.8	3.8	21.4	0.8	2.5	2.2	2.2	3.2	3.9	2.1	3.2	20.1
31	2.5	2.2	2.9	3.2	2.5	2.5	1.7	1.2	18.7									

Day	July 1945 Values K_M								Sum	August 1945 Values K_M								Sum
1	4.5	3.7	4.3	4.1	4.2	3.9	3.4	2.6	30.7	0.6	1.1	1.1	1.5	1.6	1.4	2.7	2.6	12.6
2	4.1	2.4	1.6	2.2	2.5	2.1	1.5	2.1	18.5	4.1	4.2	2.0	2.7	2.8	2.4	2.3	2.2	22.7
3	2.7	2.7	2.1	2.0	1.8	1.3	1.4	1.6	15.6	2.3	2.0	1.8	1.3	1.9	1.7	1.5	1.6	14.1
4	1.4	2.2	3.5	4.0	3.7	3.4	2.2	2.9	23.3	1.6	1.4	1.5	1.7	1.0	1.0	0.7	1.9	10.8
5	3.1	3.1	3.2	3.8	2.2	1.6	2.0	3.1	22.1	1.3	2.1	2.3	2.7	2.8	2.9	2.2	0.8	17.1
6	3.0	3.9	4.7	4.3	2.9	3.3	2.1	2.0	26.2	2.4	3.2	2.3	2.2	2.1	2.0	1.6	1.7	17.5
7	1.8	2.2	1.7	1.6	2.7	1.9	2.5	3.2	17.6	1.3	1.3	2.0	2.4	1.8	1.8	1.9	2.3	14.8
8	2.8	3.6	2.8	2.6	2.5	2.3	2.3	2.5	21.4	2.0	1.1	0.9	1.4	1.7	2.8	1.8	1.8	13.5
9	2.5	1.6	1.9	1.5	2.1	1.9	1.4	1.6	14.5	1.6	1.0	1.1	0.9	1.4	1.2	0.9	0.9	9.0
10	1.2	1.3	0.8	1.1	1.4	1.7	1.7	1.1	10.3	0.7	0.8	1.0	0.8	1.0	1.0	0.8	1.3	7.4
11	1.0	1.3	1.6	1.1	1.1	1.5	1.3	1.6	10.5	1.8	1.0	1.0	1.2	1.3	1.7	1.7	2.4	12.1
12	1.6	2.2	1.8	1.5	1.4	1.3	1.1	1.2	12.1	2.0	1.6	2.1	1.9	1.6	1.6	1.4	1.4	13.6
13	1.4	1.5	1.6	1.7	1.5	0.9	0.7	1.2	10.5	1.8	2.0	3.2	3.3	3.3	2.5	1.2	2.6	19.9
14	1.1	2.1	1.1	2.0	1.7	1.1	0.8	0.8	10.7	2.5	3.1	3.0	3.2	2.9	2.8	3.4	1.6	22.5
15	0.8	1.0	0.8	1.1	1.2	1.4	1.0	0.9	8.2	2.2	1.7	2.2	3.0	2.0	2.1	2.2	3.0	18.4
16	1.5	1.4	1.0	1.8	2.7	2.6	2.7	2.9	16.6	3.1	1.7	1.7	1.3	1.8	1.7	1.4	1.3	14.0
17	1.7	1.6	2.9	2.6	1.8	3.8	3.9	2.8	21.1	1.0	1.3	1.5	2.1	1.9	2.1	2.0	0.9	12.8
18	2.4	2.5	2.4	2.7	2.3	1.4	1.4	1.7	16.8	0.6	0.7	1.0	1.1	1.1	1.0	1.2	0.6	7.3
19	2.9	2.7	1.8	2.4	1.3	0.9	1.2	2.2	15.4	0.9	1.1	1.5	1.1	0.6	0.7	1.0	0.9	7.8
20	0.9	0.8	0.9	0.9	1.5	1.0	0.7	1.2	7.9	0.9	0.8	0.8	0.8	0.9	0.7	0.5	0.7	6.1
21	1.2	1.4	1.0	1.2	1.5	1.7	0.7	0.9	9.6	1.0	1.3	1.2	2.9	3.1	2.3	1.7	0.9	14.4
22	1.4	1.0	0.9	1.2	1.3	1.4	1.6	0.8	9.6	0.5	0.9	1.8	1.2	1.7	3.9	3.6	2.9	16.5
23	1.0	1.4	0.9	0.7	2.2	2.7	2.9	4.8	16.6	4.1	3.3	2.1	2.3	2.1	1.8	0.8	1.1	17.6
24	3.4	2.1	2.2	2.2	2.1	1.6	1.9	0.9	16.4	0.9	1.8	1.3	0.7	0.6	1.1	0.8	0.4	7.6
25	1.8	1.5	1.1	1.7	1.0	1.0	1.3	1.7	11.1	0.4	1.2	2.2	1.3	1.0	1.1	0.8	0.5	8.5
26	0.9	1.5	1.5	1.9	1.8	1.8	1.6	1.1	12.1	0.7	1.1	1.4	1.2	1.6	1.3	0.9	1.0	9.2
27	0.8	0.7	0.6	0.8	0.9	1.2	0.6	0.4	6.0	1.3	1.5	1.4	1.5	1.4	2.3	2.6	2.5	14.5
28	1.8	2.2	3.3	3.5	3.6	2.1	2.1	2.7	21.3	5.5	5.3	2.6	2.2	2.7	2.9	3.6	2.1	26.9
29	3.0	1.4	1.5	1.8	2.0	2.4	1.8	3.1	17.0	2.1	2.0	2.8	2.5	1.8	1.3	1.0	1.4	14.9
30	3.6	4.0	2.5	2.1	3.2	2.3	1.8	2.5	22.0	0.7	0.8	0.8	1.1	1.0	1.6	1.5	1.1	8.6
31	2.8	1.7	1.0	0.8	0.7	0.5	0.3	0.9	8.7	1.1	1.4	1.1	0.8	0.8	0.8	1.8	1.8	9.6

Table 1--Mean K-indices from thirty observatories, 1945--concluded

Day	September 1945									October 1945								
	Values K_M								Sum	Values K_M								Sum
1	1.1	0.7	0.8	1.3	1.5	1.5	2.4	2.2	11.5	2.3	1.5	1.0	1.4	1.0	1.7	2.9	2.1	13.9
2	2.4	2.0	2.5	2.1	1.8	1.3	1.2	1.6	14.9	0.5	1.3	2.0	2.1	2.7	1.8	0.7	0.5	11.6
3	1.3	0.9	1.0	1.5	1.7	1.2	1.1	1.6	10.3	1.1	0.6	0.9	0.8	1.5	1.5	0.5	0.4	7.3
4	2.9	2.5	4.2	4.0	3.4	2.4	2.9	2.2	24.5	0.8	0.7	0.5	0.5	0.5	0.7	1.2	1.5	6.4
5	2.1	1.7	2.1	2.0	1.9	2.9	2.0	1.5	16.2	1.7	1.7	2.0	2.3	2.3	2.9	2.7	2.6	18.2
6	2.1	1.8	1.3	2.2	2.1	1.1	1.4	2.0	14.0	1.4	0.6	0.8	1.2	1.3	1.5	1.8	1.9	10.5
7	1.4	1.3	2.1	1.6	1.9	1.3	1.1	1.6	12.3	1.5	0.6	1.2	0.9	1.5	0.8	3.2	4.0	13.7
8	1.0	0.9	0.9	1.1	0.9	1.1	2.6	2.9	11.4	2.5	1.5	2.3	2.8	2.8	3.0	1.4	1.3	17.6
9	2.1	1.3	1.7	1.1	2.0	1.6	0.9	1.9	12.6	1.5	2.4	2.5	1.9	1.3	1.6	0.6	0.5	12.3
10	0.9	0.4	1.0	1.4	1.2	1.3	1.8	1.0	9.0	0.5	0.6	0.6	1.1	1.3	0.8	0.5	0.4	5.8
11	1.5	1.0	1.5	1.7	1.8	2.6	3.6	3.6	17.3	0.4	0.3	0.6	0.7	0.7	0.5	0.7	1.2	5.1
12	4.0	3.1	2.4	2.5	3.2	1.7	1.9	1.0	19.8	1.0	1.0	2.7	4.8	4.8	4.5	3.9	3.3	26.0
13	1.2	1.4	2.0	2.1	2.7	2.2	3.1	1.7	16.4	2.7	2.2	3.7	2.7	1.7	1.4	1.5	2.3	18.2
14	2.0	1.2	0.7	0.7	1.1	0.9	1.3	0.7	8.6	1.6	1.0	2.2	1.4	2.2	2.8	2.7	2.7	16.6
15	1.1	1.0	1.4	1.9	1.0	0.7	1.2	1.0	9.3	1.4	1.5	1.6	2.6	2.4	2.3	1.7	1.7	15.2
16	1.1	1.2	1.4	1.8	1.6	2.3	1.7	2.7	13.8	1.2	2.4	2.8	2.5	4.1	3.3	2.8	1.0	20.1
17	4.0	4.1	3.6	4.8	4.1	4.0	3.6	3.7	31.9	0.7	0.9	2.2	3.0	1.7	2.8	2.9	1.7	15.9
18	3.7	3.4	3.8	4.1	3.9	5.3	4.0	3.9	32.1	1.8	1.8	2.3	2.6	2.3	1.6	1.9	1.3	15.6
19	4.5	1.6	2.2	2.9	1.3	1.6	2.2	1.7	18.0	1.6	0.8	1.3	2.1	2.4	2.1	3.0	3.5	16.8
20	1.9	2.3	2.1	3.4	1.6	1.8	1.7	0.5	15.3	3.1	2.1	1.2	1.1	1.8	1.3	2.7	2.7	16.0
21	0.9	0.8	0.9	1.7	2.9	2.7	2.2	2.6	14.7	1.0	0.6	0.8	1.3	1.2	1.8	1.7	2.4	10.8
22	1.9	2.1	1.0	1.3	1.5	1.5	1.1	0.8	11.2	0.9	0.4	0.8	1.8	2.9	2.9	2.2	2.3	14.2
23	1.1	0.9	0.9	0.7	0.7	0.6	0.7	0.4	6.0	1.4	0.8	1.1	1.5	1.3	1.6	1.2	2.4	11.3
24	0.6	0.6	0.7	0.8	0.7	1.2	1.4	0.8	6.8	3.1	3.2	3.7	5.1	5.3	4.9	5.1	4.1	34.5
25	0.7	2.0	2.0	2.7	2.3	1.9	2.1	2.2	15.9	4.7	4.3	3.1	4.4	4.3	4.0	3.0	1.9	29.7
26	1.6	1.0	1.2	1.5	1.7	2.4	2.0	1.6	13.0	1.9	0.9	0.8	0.8	1.0	0.9	0.6	1.1	8.0
27	1.6	2.6	1.6	3.9	3.4	1.7	1.9	1.6	18.3	0.8	1.0	1.4	1.3	2.2	2.5	2.9	4.6	16.7
28	1.7	2.2	1.5	1.9	1.3	1.3	1.8	0.9	12.6	4.8	4.0	1.9	2.8	2.9	3.6	4.2	3.3	27.5
29	1.0	1.5	1.7	0.9	0.7	2.4	2.1	1.6	11.9	2.4	1.8	1.3	1.9	2.2	2.5	2.2	2.9	17.2
30	2.9	2.1	3.7	3.1	2.9	2.2	3.1	2.6	22.6	1.4	0.8	1.1	1.7	3.3	1.9	1.4	1.3	12.9
31										1.4	1.2	0.8	1.1	1.2	1.0	1.5	1.8	10.0

Day	November 1945									December 1945								
	Values K_M								Sum	Values K_M								Sum
1	1.0	0.7	1.0	0.8	0.8	0.7	0.7	1.1	6.8	0.7	1.0	0.6	0.7	0.7	0.9	0.7	0.6	5.9
2	1.0	0.5	0.8	0.6	0.8	0.9	1.2	0.6	6.4	0.6	1.3	0.8	0.7	1.1	1.2	0.8	2.3	8.8
3	0.6	1.2	1.1	1.1	1.0	0.8	0.6	1.5	7.9	1.3	0.5	0.8	0.7	1.0	0.7	0.7	0.8	6.5
4	1.2	0.7	0.8	0.7	2.8	1.8	2.1	2.7	12.8	0.9	0.6	0.4	0.4	0.5	0.5	0.5	0.3	4.1
5	3.3	2.3	1.1	2.6	2.3	1.5	0.7	0.8	14.6	0.8	1.1	1.0	1.0	0.7	1.6	2.9	2.6	11.7
6	0.4	0.7	1.2	1.0	0.9	0.9	0.8	0.4	6.3	2.1	1.8	1.9	2.0	3.4	2.4	3.0	2.7	19.3
7	0.5	0.7	0.9	0.7	0.7	1.2	1.2	1.2	7.1	2.6	1.8	2.4	1.8	0.9	0.8	1.5	2.9	14.7
8	0.4	0.7	0.8	1.2	2.1	3.7	3.5	2.7	15.1	2.9	3.2	2.5	2.7	3.2	2.1	1.8	1.7	20.1
9	3.3	3.5	5.0	4.8	3.6	3.8	3.6	2.8	30.4	2.7	1.7	2.6	2.3	2.4	3.0	1.6	1.8	18.1
10	3.3	3.0	2.9	2.0	2.0	1.0	0.8	1.8	16.8	1.3	1.9	1.6	2.1	1.6	1.3	0.8	0.7	11.3
11	2.0	2.8	3.5	2.6	3.4	2.4	2.8	1.4	20.9	1.1	0.8	1.6	1.5	1.5	0.8	0.8	0.4	8.5
12	3.0	3.6	2.8	3.4	1.6	1.8	3.7	1.9	21.8	0.6	0.7	0.7	1.0	2.0	0.9	1.4	1.2	8.5
13	1.8	2.6	2.8	1.8	2.2	2.2	2.1	2.2	17.7	0.7	0.7	0.6	1.0	3.6	3.7	[illegible]	4.6	19.2
14	1.8	1.2	1.3	2.0	1.6	1.8	2.2	1.2	13.7	4.9	5.1	4.9	5.8	5.7	4.2	1.8	1.3	33.7
15	1.2	1.3	2.8	2.4	2.2	2.8	2.6	1.8	17.1	0.9	1.5	2.2	1.6	2.4	2.0	1.7	[illegible]	15.3
16	1.8	1.5	2.0	2.8	2.9	2.6	2.7	3.5	19.8	1.7	1.0	0.7	0.7	0.3	[illegible]	[illegible]	[illegible]	9.6
17	2.5	1.7	2.4	3.0	3.2	1.0	0.8	0.4	15.0	3.8	2.9	2.5	3.0	3.2	3.7	1.5	1.7	21.6
18	0.7	1.3	0.9	1.4	1.4	0.8	1.1	0.6	8.2	1.5	0.8	1.2	1.1	[illegible]	1.4	1.5	1.3	10.8
19	0.9	0.6	0.8	0.7	1.5	1.1	1.3	0.6	7.5	1.3	1.1	1.6	1.5	[illegible]	2.1	3.7	5.2	17.5
20	0.7	1.4	0.8	1.0	1.0	0.6	0.6	0.8	6.9	4.0	3.2	3.7	2.7	2.4	3.0	3.7	3.4	26.1
21	0.8	0.7	0.8	1.0	1.2	1.2	1.8	2.0	9.5	4.0	4.3	2.8	2.9	[illegible]	1.1	[illegible]	[illegible]	[illegible]
22	2.2	1.8	0.7	0.5	0.6	0.7	0.8	1.0	8.3	1.1	0.9	0.7	0.4	0.5	0.7	0.7	[illegible]	[illegible]
23	1.0	1.0	0.9	0.8	1.1	1.5	1.6	0.5	8.4	1.3	0.9	0.8	0.6	1.1	2.4	[illegible]	4.1	15.1
24	0.5	1.0	0.7	1.5	0.7	0.5	0.6	0.7	6.2	3.0	2.0	2.7	3.8	3.9	3.9	1.5	[illegible]	21.3
25	1.1	0.7	0.7	1.0	1.3	1.5	2.2	1.5	10.0	0.8	0.7	2.9	3.4	4.2	4.7	[illegible]	[illegible]	24.3
26	0.8	0.8	0.6	0.6	1.0	0.8	0.6	1.0	6.2	3.7	3.6	3.1	3.8	3.5	[illegible]	[illegible]	[illegible]	[illegible]
27	0.8	1.2	0.9	0.7	0.7	0.7	1.4	1.7	8.1	2.5	3.0	2.7	3.2	4.3	3.5	4.3	[illegible]	[illegible]
28	0.6	1.2	1.3	0.8	0.7	1.1	1.5	2.0	9.2	3.0	3.0	2.9	2.9	4.1	4.7	[illegible]	[illegible]	[illegible]
29	1.9	2.3	2.8	2.4	2.3	1.6	2.9	2.0	18.2	1.7	3.1	2.3	2.7	2.2	2.6	[illegible]	[illegible]	[illegible]
30	1.3	1.2	0.6	1.0	0.8	0.5	0.7	1.0	7.1	1.9	1.8	1.6	2.2	1.7	0.9	1.5	0.9	12.5
31										1.9	1.5	2.3	1.7	2.7	1.4	1.2	2.1	14.8

TABLE 2—*Mean K-indices by months from thirty observatories, 1945*

Month	Mean indices, K_M, for GMT 3-hour interval								
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	Mean
January	1.78	1.69	1.57	1.78	1.85	1.89	2.02	1.80	1.80
February	1.83	1.82	1.73	1.99	1.94	2.04	2.13	1.86	1.92
March	2.22	1.98	2.12	2.57	2.52	2.65	2.42	2.38	2.36
April	1.98	1.91	2.15	2.24	2.25	2.17	1.96	2.00	2.08
May	1.98	2.06	2.05	1.99	2.06	2.32	2.19	2.12	2.10
June	1.54	1.81	1.81	1.69	1.80	1.69	1.58	1.54	1.68
July	2.07	2.02	1.90	2.03	2.03	1.87	1.67	1.90	1.94
August	1.71	1.74	1.70	1.75	1.72	1.79	1.66	1.55	1.70
September	1.88	1.65	1.80	2.09	1.96	1.89	2.00	1.80	1.88
October	1.71	1.44	1.65	2.01	2.20	2.15	2.11	2.09	1.92
November	1.41	1.46	1.54	1.56	1.61	1.45	1.64	1.45	1.52
December	1.98	1.85	1.91	2.00	2.25	2.12	2.05	2.10	2.03
Year	1.84	1.79	1.83	1.98	2.02	2.00	1.95	1.88	1.91

TABLE 3—*Mean K-indices by years from 1940 to 1945*

Number of observatories	Year	Mean indices, K_M, for GMT 3-hour interval								
		00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	Mean
27	1940	2.12	2.05	1.95	2.09	2.24	2.29	2.34	2.22	2.16
29	1941	2.21	2.14	2.20	2.28	2.31	2.34	2.39	2.35	2.28
28	1942	2.14	2.08	2.13	2.29	2.38	2.37	2.28	2.22	2.24
27	1943	2.40	2.35	2.49	2.60	2.53	2.48	2.42	2.36	2.45
30	1944	1.96	1.87	1.93	2.04	2.06	2.03	1.96	1.95	1.98
30	1945	1.84	1.79	1.83	1.98	2.02	2.00	1.95	1.88	1.91
Mean		2.11	2.05	2.09	2.21	2.26	2.25	2.22	2.16	2.17

TABLE 4—*Monthly means of u derived from horizontal-intensity records for Cheltenham, Honolulu, Huancayo, San Juan, Tucson, and Watheroo for January 1939, to December, 1945*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1939	0.68	1.83	1.01	1.61	1.61	1.03	1.44	1.96	1.38	1.62	0.93	0.82	1.33
1940	1.40	0.79	2.46	1.57	1.15	1.54	0.92	0.94	1.16	1.37	1.44	0.79	1.29
1941	0.92	0.86	2.38	0.95	0.87	0.83	2.49	1.31	2.23	1.15	1.50	0.92	1.37
1942	0.78	1.22	1.29	1.46	1.06	0.79	0.84	0.62	0.64	1.12	0.88	0.78	0.96
1943	0.78	0.99	1.04	1.17	0.90	0.83	0.70	1.09	0.87	0.72	0.87	0.79	0.90
1944	0.62	0.82	0.90	0.95	0.61	0.70	0.56	0.87	0.66	0.79	0.74	1.32	0.80
1945*	(1.02)	(0.73)	(0.84)	(0.92)	(0.62)	(0.54)	(1.00)	(0.88)	(0.90)	(0.88)	(0.92)	(1.15)	(0.87)

*Preliminary means for 1945, based on Huancayo and Watheroo records only.

Table 5—*Preliminary International Character-Figures, C, for 1945*
(Data from 41 observatories)

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.7	0.1	0.1	1.6	0.5	0.0	1.4	0.3	0.2	0.4	0.0	0.0
2	0.4	0.8	0.3	0.7	0.5	0.0	0.6	1.0	0.3	0.2	0.1	0.2
3	0.6	0.2	0.5	0.1	0.5	0.1	0.3	0.2	0.1	0.0	0.1	0.0
4	0.7	0.1	0.1	0.5	0.2	0.1	1.0	0.2	1.0	0.0	0.4	0.0
5	0.2	0.9	1.2	0.9	0.1	0.2	0.8	0.6	0.3	0.7	0.5	0.4
6	0.2	0.7	1.0	1.1	0.2	1.2	1.2	0.4	0.2	0.2	0.0	0.8
7	0.2	0.3	0.4	0.8	0.1	0.8	0.6	0.4	0.2	0.7	0.1	0.4
8	0.1	0.8	1.1	0.8	0.1	1.0	0.6	0.3	0.4	0.6	0.9	0.7
9	0.8	0.8	0.4	0.0	0.8	0.7	0.2	0.1	0.2	0.2	1.6	0.6
10	1.2	0.4	0.2	0.1	0.8	0.7	0.2	0.1	0.1	0.0	0.4	0.0
11	0.0	0.5	1.4	1.5	1.1	0.5	0.1	0.3	0.8	0.0	1.0	0.0
12	0.3	0.2	1.7	1.3	0.6	0.2	0.1	0.2	0.7	1.5	0.9	0.1
13	0.4	0.0	0.3	0.6	0.4	0.2	0.1	0.8	0.5	0.5	0.6	1.3
14	0.1	0.4	0.6	0.9	0.5	0.1	0.1	1.0	0.0	0.6	0.3	1.8
15	1.7	1.2	1.7	0.6	0.0	0.1	0.0	0.6	0.0	0.4	0.5	0.5
16	0.6	1.1	1.1	0.2	0.2	0.1	0.6	0.5	0.3	1.0	0.9	0.2
17	0.9	0.8	0.5	0.1	0.3	0.4	1.0	0.2	1.6	0.6	0.4	0.8
18	0.3	0.2	0.5	0.1	0.7	0.2	0.4	0.0	1.6	0.2	0.0	0.1
19	0.5	0.1	0.1	0.6	0.4	0.1	0.3	0.0	0.7	0.7	0.1	1.1
20	0.4	0.1	1.1	0.6	0.4	0.3	0.0	0.0	0.4	0.5	0.0	1.2
21	0.3	0.0	0.5	0.1	0.4	0.1	0.1	0.4	0.4	0.2	0.2	0.7
22	0.0	0.4	0.0	0.5	0.1	0.1	0.1	1.0	0.1	0.5	0.1	0.0
23	0.0	0.5	0.0	0.6	0.3	0.1	0.9	0.7	0.0	0.1	0.2	0.9
24	0.0	0.3	0.6	0.8	0.4	0.0	0.5	0.1	0.0	1.8	0.0	1.0
25	0.0	0.7	0.6	0.2	0.6	0.2	0.1	0.1	0.5	1.5	0.1	1.4
26	0.6	1.2	1.6	0.0	0.3	0.0	0.1	0.1	0.2	0.1	0.0	1.1
27	0.2	1.0	1.1	0.1	0.4	0.6	0.1	0.4	0.5	1.0	0.1	1.2
28	1.1	0.5	1.7	0.0	0.2	0.3	0.7	1.5	0.2	1.3	0.1	1.0
29	1.6		0.7	0.3	0.4	0.0	0.5	0.4	0.3	0.5	0.6	0.5
30	0.7		0.1	0.7	0.8	0.8	0.7	0.1	0.8	0.3	0.1	0.2
31	0.1		0.1		0.4		0.3	0.2		0.1		0.3
Mean	0.48	0.51	0.69	0.55	0.41	0.31	0.44	0.39	0.42	0.53	0.34	0.60

Mean for year: 0.47

activity since these published values, the monthly and annual means of u derived from horizontal-intensity records for Cheltenham, Honolulu, Huancayo, San Juan, Tucson, and Watheroo observatories are given in Table 4 through the year 1944; also added are preliminary means for 1945

based only on Huancayo and Watheroo records, others not being available in entirety for 1945.

Character-figures on a scale of 0, 1, and 2 have been received from 41 observatories. *Preliminary* international character-figures, C, for 1945 are given in Table 5. The average for the year is 0.47 as compared with a value of 0.52 for 1944 from 43 observatories.

The accumulation of further data has not altered the indications as to the occurrence of the last sunspot-minimum (see *Terr. Mag.*, **51**, 58, 1946).

It might be well to emphasize a few points in connection with this phase of magnetic work. So long as it remains necessary for magnetic measurements to be made in the magnetic field of the Earth, knowledge of prevailing magnetic conditions is necessary. Generally speaking, continuous records from observatories are not readily and promptly available, nor is it practicable to give wide circulation to magnetograms. Predictions based on laws and theories are not yet entirely dependable. Hence the importance attached to direct indexing of magnetic conditions can readily be understood. The comparatively recent formulation and adoption (figures are available beginning with 1938) of the three-hour-range indices K brought about a complete and homogeneous description of magnetic activity. The main advantages of K_M over C_M are (1) the shorter interval for K_M and (2) the definite, fixed standards for K. The compilations of K-indices over the years reflect well-marked individuality as well as conspicuous average properties of magnetic disturbances. None the less valuable, however, are the international daily magnetic characters, C. They are available over a long period of time, beginning with 1884. Graphic estimation in the assigning of C has been subject to some criticism, but one must concede that the individual differences lend great significance to the average C_M. In reality, a fine gradation of C_M between 0.0 and 2.0, so useful in describing and comparing the degree of magnetic activity day by day, is obtained.

In conclusion, the writer would like to express his appreciation of the splendid cooperation given at all times by various organizations and observatories. Grateful acknowledgment is also made of the assistance of Miss E. Balsam in compiling data.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., January 21, 1947

NOTES

(See also pages 70 and 96)

1. *Discontinuance of variometers at Dehra Dun Observatory*—Dr. S. K. Chakrabarty, Director of the Colaba and Alibag Observatories of the Meteorological Department of India, informs us that the variometers at Dehra Dun Observatory have ceased functioning since August, 1943.

2. *Toolangi Observatory*—The Toolangi Observatory which is at present operated by the Commonwealth Observatory, Canberra, will in the near future be transferred to the Department of Mines and Resources.

3. *Volcanological Laboratory at Rotorua*—The New Zealand Department of Scientific and Industrial Research is planning to establish, at Rotorua, in the North Island, New Zealand, a volcanological laboratory, as well as a number of seismological stations at various points to measure disturbances up to about 50 miles. It is also proposed to study at closer range with seismometers, geophones, etc., more local disturbances in thermal regions.

4. *Regional Meteorological Service of the Azores*—The former Meteorological Service of the Azores is now, as Regional Meteorological Service of the Azores, a branch of the newly formed National Meteorological Service of Portugal in Lisbon. It is under the direction of Dr. H. Amorim Ferreira, to whom all matters concerned with meteorologcal and geophysical activities in Portugal and the Azores should be referred. Lieutenant-Colonel J. Agostinho, is Chief of the Regional Meteorological Service of the Azores.

5. *Pacific Science*—There was published by the University of Hawaii in January, 1947, the first issue of an illustrated quarterly devoted to the biological and physical sciences of the Pacific area. This magazine offers an opportunity for scientists to publish research papers and notes on the Pacific region. The editorial board consists of specialists from the University of Hawaii and other Island institutions. *Pacific Science* will be issued in January, April, July, and October each year. Contributions should be addressed to A. Grove Day at the University and subscriptions ($3.00 a year) may be placed through the University Office of Publications.

6. *American Section, International Scientific Radio Union*—The annual joint meeting of the American Section of the International Scientific Radio Union and the Institute of Radio Engineers will be held in Washington, D. C., May 5, 6, and 7, 1947.

7. *Solar Eclipse, May 20, 1947*—The National Geographic Society and the Army Air Forces will join in an expedition to the interior of Brazil, near the town of Bocayuva, to observe the total eclipse of the Sun on May 20, 1947. Lyman J. Briggs, former Director of the National Bureau of Standards and now Chairman of the National Geographic Society's Research Committee, will head the expedition. Scientists from the National Bureau of Standards, Lick Observatory, Yerkes Observatory, Georgetown Observatory, and the Naval Research Laboratory will participate.

DAILY INTERNATIONAL MAGNETIC CHARACTER-FIGURES, *C*, FOR THE YEARS 1884 TO 1889

BY J. BARTELS

The long series of International magnetic character-figures *C* extends from 1884. The figures for 1884-89, as far as is known have never been published. The values for the six years are submitted therefore for publication in the JOURNAL.

Day	Year 1884											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.0	0.5	1.8	0.7	1.6	0.9	0.5	0.3	0.2	1.0	1.0	0.7
2	0.1	1.0	1.6	0.4	0.1	1.3	1.5	0.4	0.2	2.0	2.0	0.2
3	0.1	0.3	1.8	0.7	0.1	1.0	2.0	0.3	0.6	1.2	2.0	0.1
4	0.1	1.0	0.7	0.5	0.1	0.7	1.4	0.1	0.1	0.7	1.2	0.1
5	0.3	0.9	0.2	0.2	0.0	0.3	0.8	0.1	0.1	0.5	0.1	0.1
6	0.1	0.5	0.5	0.3	0.3	0.7	0.8	0.3	0.6	0.9	0.7	0.1
7	0.2	0.6	1.1	0.3	0.8	0.4	0.7	0.5	0.5	1.4	0.6	0.1
8	0.8	0.8	0.9	0.1	0.5	0.0	1.0	1.4	0.2	0.2	0.4	0.9
9	0.5	0.7	0.8	0.1	0.1	0.2	0.4	1.5	0.0	0.5	0.9	0.7
10	0.7	0.1	0.2	1.3	1.2	0.5	0.2	1.0	1.1	0.5	0.9	0.1
11	0.9	0.1	0.2	1.4	1.3	0.3	0.4	0.5	1.1	0.1	0.9	1.0
12	0.8	0.1	0.0	0.8	1.0	0.4	0.4	0.5	0.5	0.0	0.4	0.3
13	0.5	0.0	0.1	0.4	0.6	0.7	1.0	1.0	1.1	0.1	0.5	0.0
14	0.1	0.0	0.5	0.7	0.4	0.7	1.5	0.8	1.5	1.1	0.4	1.3
15	0.3	0.0	0.5	1.0	0.7	0.3	0.6	0.8	0.7	1.1	0.1	1.6
16	0.1	0.5	0.7	0.9	0.2	0.0	0.7	0.2	0.1	0.7	0.1	1.1
17	0.4	0.7	0.5	1.1	0.1	0.8	0.1	0.0	1.4	1.0	1.0	0.4
18	0.6	0.8	0.1	1.6	0.1	1.0	0.0	0.1	1.9	0.3	0.9	0.2
19	0.7	0.6	1.0	1.1	0.6	1.2	0.5	0.2	1.2	0.9	0.9	0.5
20	0.1	0.1	1.4	1.1	0.1	0.2	0.9	0.8	0.4	0.4	0.5	1.1
21	0.5	0.2	1.0	0.8	0.0	0.1	0.1	1.4	0.4	0.6	0.1	0.7
22	0.1	0.2	0.8	0.5	1.0	1.0	0.0	1.3	0.3	0.0	0.0	1.1
23	0.3	1.0	0.9	0.3	0.9	1.9	0.4	0.8	0.0	0.1	1.1	1.2
24	0.1	1.6	0.9	1.3	0.5	1.0	0.3	0.4	0.1	0.2	1.2	0.6
25	0.8	1.4	0.5	1.3	0.1	0.2	1.1	0.5	0.1	0.8	0.7	0.4
26	1.2	0.9	0.6	1.1	0.1	0.0	1.2	0.5	0.3	0.9	0.1	0.1
27	0.7	0.7	1.0	0.8	0.1	0.1	0.7	0.2	0.0	0.1	0.2	0.3
28	0.1	0.2	1.2	0.6	0.3	0.8	0.3	0.0	0.1	0.6	1.5	1.2
29	0.1	1.3	1.7	0.3	0.1	0.7	1.0	0.1	0.1	1.4	0.9	0.7
30	0.1		0.7	0.3	0.1	0.5	0.6	0.1	0.7	0.4	0.5	0.3
31	0.1		0.6		0.6		0.4	0.1		0.0		0.4
Mean	0.37	0.58	0.78	0.73	0.44	0.60	0.69	0.52	0.52	0.63	0.73	0.57

Mean for 1884: 0.59

Day	Year 1885											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.2	0.1	1.1	1.1	0.0	0.3	1.2	1.8	0.7	0.6	0.9	0.9
2	1.6	0.1	0.8	0.7	0.7	0.4	0.2	1.2	0.7	0.6	0.1	0.5
3	0.8	0.3	0.8	1.2	0.2	0.1	0.1	0.9	0.7	0.5	0.1	0.3
4	0.4	0.7	0.4	0.4	0.4	1.0	0.7	0.9	1.6	0.0	0.1	0.0
5	0.0	1.3	0.2	0.1	0.5	0.6	0.9	0.5	1.5	0.1	0.1	0.1
6	0.4	1.0	0.5	0.2	0.7	0.1	1.0	0.4	0.9	0.2	0.4	1.5
7	0.6	0.4	0.7	0.3	0.5	0.1	0.4	1.4	0.5	0.4	1.1	1.7
8	1.0	0.9	0.2	1.0	0.5	0.1	0.4	0.9	0.9	0.7	0.9	1.4
9	1.3	0.6	0.0	0.6	0.2	0.5	0.4	0.4	0.6	0.9	0.7	0.9
10	1.1	1.6	0.1	0.5	1.6	0.9	0.5	0.5	0.4	0.3	1.5	0.3
11	0.8	0.6	0.1	0.7	1.5	0.8	0.8	0.5	0.4	0.4	1.8	0.1
12	0.7	1.7	0.6	0.7	1.1	0.7	0.5	0.7	0.6	0.7	0.8	0.0
13	0.4	1.1	1.2	1.1	1.8	0.6	0.5	0.0	0.3	1.1	0.3	0.1
14	0.1	0.5	1.0	0.6	1.3	0.4	0.3	0.1	0.6	1.0	0.2	0.5
15	0.1	0.2	2.0	1.1	0.7	0.3	0.5	0.3	1.5	1.3	0.1	0.2
16	0.4	0.3	1.4	1.0	0.7	0.6	0.4	0.9	1.7	1.3	0.1	0.2
17	0.7	0.9	0.4	0.9	0.7	0.4	1.0	0.1	1.1	0.5	0.0	0.3
18	0.9	1.1	0.1	0.5	0.7	0.9	1.2	0.1	0.9	0.9	1.4	0.5
19	0.6	0.5	0.1	0.9	0.2	0.7	0.7	0.2	0.5	0.7	0.9	0.4
20	0.3	0.1	1.0	0.9	0.5	1.6	0.2	0.9	0.2	0.5	0.7	0.6
21	0.4	0.9	0.9	0.7	0.1	0.5	0.4	1.1	0.3	0.1	0.1	0.5
22	1.7	1.0	0.5	0.0	0.0	1.0	0.4	0.7	1.3	0.9	0.4	0.6
23	1.0	0.3	0.6	0.1	0.2	0.9	0.2	0.1	1.6	1.2	0.1	0.1
24	0.3	0.0	0.1	0.7	0.7	0.8	0.3	0.0	0.8	0.7	0.2	0.1
25	0.2	0.0	0.1	0.3	1.8	2.0	1.1	0.1	1.0	0.4	0.5	0.1
26	0.0	0.1	0.1	0.8	1.9	1.2	0.2	0.6	0.9	0.1	0.5	0.2
27	0.4	1.4	0.1	1.2	1.7	0.1	0.6	0.9	1.2	0.8	0.4	0.1
28	0.5	1.6	0.5	1.7	1.8	0.2	0.9	1.6	0.7	0.8	0.2	0.9
29	0.5		0.1	0.3	0.9	0.0	0.5	1.5	0.4	0.8	0.1	0.7
30	1.6		0.0	0.1	1.1	0.0	0.5	0.9	0.8	0.7	0.1	0.7
31	0.2		0.3		0.8		0.5	0.9		0.9		0.2
Mean	0.62	0.69	0.52	0.68	0.82	0.85	0.56	0.67	0.84	0.65	0.49	0.47

Mean for 1885: 0.66

Day	Year 1886											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.7	0.4	0.2	1.1	1.0	0.2	1.3	0.7	0.3	0.6	0.0	1.4
2	1.1	0.8	0.2	0.4	1.0	0.1	0.9	0.6	0.2	0.7	1.3	1.5
3	1.0	0.9	1.0	0.2	0.9	0.5	0.9	0.4	0.3	0.4	1.8	1.1
4	1.1	0.7	0.6	0.5	0.6	0.9	0.7	0.2	0.4	0.1	1.7	1.1
5	0.8	1.4	0.2	0.5	0.3	1.1	0.5	0.3	0.3	0.3	1.7	1.1
6	0.1	0.3	0.6	0.3	0.6	1.0	0.3	0.8	0.2	1.7	1.7	0.9
7	0.2	0.5	1.1	0.4	0.2	0.9	0.0	1.0	0.7	1.8	1.2	0.9
8	0.5	0.8	0.2	0.2	1.4	1.1	0.4	0.5	0.5	1.9	1.0	0.9
9	2.0	0.1	0.3	0.0	2.0	0.9	0.7	0.1	1.3	1.7	0.6	0.3
10	1.1	1.0	0.7	0.0	1.6	0.5	0.6	0.2	1.8	1.6	0.3	0.1
11	0.5	1.6	0.6	0.9	1.3	0.3	0.7	0.9	1.7	1.0	0.5	0.7
12	0.1	0.2	0.5	1.4	1.2	1.4	0.6	1.8	1.5	1.0	0.9	0.4
13	0.1	0.0	0.5	1.5	0.9	0.9	0.3	1.0	1.1	0.9	1.1	0.8
14	0.8	0.0	0.2	1.8	1.2	0.9	1.2	1.4	1.0	0.7	0.3	0.9
15	1.0	0.3	0.4	1.8	0.9	0.5	0.8	1.2	0.7	0.5	0.7	1.0
16	0.8	1.2	1.1	1.1	0.8	0.5	0.9	1.3	0.2	0.1	0.4	0.9
17	0.0	1.0	1.1	1.0	1.1	1.0	0.7	1.3	0.5	0.8	0.9	1.1
18	0.1	0.9	1.3	1.3	1.3	0.8	0.6	1.1	0.2	1.2	0.3	0.8
19	1.1	1.1	1.5	1.2	0.7	0.6	1.3	1.1	0.2	1.4	0.3	0.7
20	0.8	0.5	1.5	1.0	0.6	0.1	1.3	0.5	0.4	0.7	1.1	0.4
21	0.9	0.9	0.9	0.9	1.1	0.7	1.2	0.4	1.3	1.1	0.3	0.7
22	1.1	1.3	1.2	0.5	0.8	1.3	0.8	0.1	0.8	0.7	0.1	1.0
23	0.1	0.5	1.6	0.4	0.7	1.0	0.8	0.8	0.3	0.2	1.2	1.0
24	0.6	0.6	0.8	0.4	0.6	1.1	0.5	1.6	0.3	0.0	1.2	0.6
25	0.1	0.3	0.6	1.2	0.2	1.0	0.2	0.7	0.1	0.1	0.8	0.4
26	0.2	0.1	0.6	0.5	0.8	0.9	0.0	0.7	0.1	0.8	0.5	1.3
27	0.3	0.3	0.8	0.3	1.1	0.7	1.4	0.4	0.1	1.1	0.2	1.2
28	0.4	0.1	0.7	0.4	0.8	0.5	1.6	0.3	0.1	1.0	0.0	1.2
29	1.0		1.2	0.7	0.6	1.2	0.7	0.1	0.5	1.1	0.9	1.4
30	1.4		2.0	0.8	0.2	1.9	0.6	0.1	1.2	0.5	1.7	0.9
31	0.5		2.0		0.2		0.6	0.2		0.2		0.3
Mean	0.66	0.64	0.84	0.76	0.86	0.82	0.74	0.70	0.61	0.83	0.82	0.87

Mean for 1886: 0.76

Day	Year 1887											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.0	1.1	0.4	0.2	0.6	0.9	0.1	1.4	1.3	0.4	0.2	0.4
2	0.2	0.6	0.2	0.7	1.2	0.4	0.1	1.6	1.1	0.1	0.4	0.2
3	0.4	0.8	0.0	1.1	1.1	0.0	0.0	1.6	0.9	0.0	0.9	0.2
4	0.7	1.2	0.1	1.1	0.9	0.2	0.4	1.0	0.3	0.0	0.6	0.0
5	0.3	0.9	0.9	1.5	0.8	1.4	0.7	1.3	0.1	0.2	0.3	0.2
6	0.3	0.2	1.3	1.5	0.8	0.4	0.7	0.9	0.0	0.2	0.1	0.8
7	0.8	0.8	0.9	1.3	0.6	0.1	1.8	0.9	0.0	0.6	0.1	0.9
8	0.3	0.3	1.2	1.0	0.3	0.5	1.3	0.7	0.1	0.4	0.9	0.4
9	0.1	1.0	1.2	0.9	0.1	0.7	0.5	0.2	0.5	0.1	0.7	0.1
10	0.1	0.8	0.7	0.6	0.3	1.3	0.8	0.1	1.3	0.3	1.1	0.0
11	0.5	0.9	0.6	1.1	0.3	0.7	0.9	0.0	1.0	0.3	0.4	0.1
12	0.6	1.5	0.2	0.6	1.1	0.6	0.5	0.0	0.6	0.9	0.1	0.2
13	0.3	1.5	0.3	0.1	1.1	0.5	0.2	0.2	0.3	0.9	0.2	0.8
14	1.5	1.6	0.3	0.7	1.0	0.0	0.3	1.0	0.5	0.8	0.1	0.3
15	1.6	1.0	1.2	1.1	0.9	0.0	0.6	1.2	0.9	0.3	0.0	0.0
16	1.2	0.8	0.9	0.8	0.6	0.0	0.6	0.8	0.8	0.1	0.0	1.2
17	1.1	0.5	0.3	1.0	0.5	0.4	0.2	0.5	0.6	0.6	0.6	1.4
18	1.1	0.2	0 0	0.5	0.7	0.8	0.9	0.1	0.1	0.2	0.2	1.2
19	0.9	0.7	0.9	0.3	0.7	1.1	0.9	0.0	0.2	0.1	0.9	1.0
20	0.8	1.3	1.3	0.5	0.1	0.8	1.0	0.0	0.0	0.0	1.1	0.8
21	0.2	1.5	1.4	0.7	0.0	0.9	0.5	0.3	0.3	0.2	1.9	1.2
22	1.0	1.2	0.9	1.0	0.2	1.0	0.0	0.2	0.8	1.7	1.0	1.3
23	1.3	1.1	0.9	0.8	0.6	0.9	0.2	0.0	0.8	1.7	0.8	0.1
24	1.1	0.8	0.9	0.8	1.2	0.3	0.1	0.1	0.8	0.8	0.4	0.1
25	1.2	0.5	0.2	1.1	1.0	0.2	0.1	0.8	1.9	0.3	0.0	0.9
26	1.0	0.5	0.6	0.3	0.9	0.1	0.0	0.3	1.9	1.7	0.0	1.2
27	0.6	0.8	0.6	0.1	0.9	0.2	0.5	0.2	1.8	1.1	0.1	1.1
28	0.4	0.6	0.5	1.4	0.8	0.0	0.0	1.2	1.6	0.3	0.6	0.9
29	0.7		0.0	1.0	0.1	0.5	0.0	1.7	1.0	0.1	1.3	0.9
30	0.4		0.0	0.5	0.6	0.8	0.0	1.3	0.9	1.1	0.9	0.6
31	0.6		0.0		0.8		0.1	0.9		0.2		0.4
Mean	0.68	0.88	0.61	0.81	0.67	0.52	0.48	0.66	0.75	0.51	0.53	0.61

Mean for 1887: 0.64

Day	Year 1888											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.6	0.1	0.3	0.1	1.0	0.0	1.4	0.2	0.7	0.3	0.9	0.2
2	0.2	0.1	0.1	0.8	0.8	0.3	1.0	0.7	0.5	0.2	0.4	0.5
3	0.1	0.7	0.1	1.0	0.7	1.7	0.8	1.3	0.4	0.0	0.1	0.7
4	0.2	0.5	0.1	1.2	0.2	1.3	0.3	1.1	0.0	0.2	1.0	0.5
5	0.2	0.9	0.0	1.2	0.0	1.1	0.1	0.5	0.0	1.2	1.0	0.6
6	0.8	0.0	0.0	0.9	0.2	1.0	0.0	0.4	0.0	0.9	0.9	0.8
7	0.9	0.4	0.9	0.4	1.8	0.7	0.6	0.1	0.5	0.5	0.9	0.3
8	1.7	0.6	1.1	0.3	1.4	0.3	1.0	0.1	0.5	0.3	0.7	1.1
9	0.3	1.3	1.3	0.0	1.3	0.1	0.6	0.1	0.7	0.2	0.4	0.7
10	0.1	1.0	1.0	0.1	1.2	0.5	0.1	0.1	0.3	0.4	0.3	0.1
11	0.2	1.3	0.6	1.7	0.8	0.1	0.1	0.8	0.0	0.8	1.1	0.0
12	0.4	1.0	0.2	1.8	0.8	0.3	0.0	1.0	0.9	1.0	0.2	0.3
13	1.9	0.4	0.3	1.4	0.4	0.1	0.0	0.3	1.3	0.9	0.1	0.7
14	1.3	0.2	0.3	1.1	0.1	0.1	0.1	0.1	1.1	0.3	0.0	1.0
15	1.0	0.0	1.3	1.0	0.1	0.5	0.2	0.1	1.2	0.0	0.3	1.1
16	0.7	0.8	1.7	0.4	0.6	0.4	0.7	1.7	0.8	0.1	1.3	0.9
17	0.7	0.7	1.7	0.2	0.1	0.1	0.8	1.3	0.8	0.3	1.5	0.5
18	0.3	1.0	1.2	0.1	0.3	0.2	0.5	1.1	0.8	0.4	1.1	0.3
19	0.1	1.3	0.9	0.2	0.7	0.3	0.4	0.8	0.9	1.4	0.8	0.2
20	0.0	0.9	0.5	0.3	1.5	0.1	1.0	0.8	0.7	1.4	0.4	0.0
21	0.7	1.2	0.4	0.0	1.9	0.5	0.8	0.3	0.5	1.2	0.2	0.1
22	0.8	1.0	0.2	0.0	0.3	1.2	1.1	0.3	0.2	0.7	0.0	0.1
23	1.8	0.6	0.2	0.0	0.7	1.1	1.0	0.0	0.1	0.9	0.0	0.3
24	1.5	0.8	0.4	0.7	0.5	1.0	0.5	0.1	0.2	0.8	0.0	1.6
25	1.0	0.7	0.1	0.1	0.2	0.8	0.3	0.1	0.7	0.9	0.6	1.0
26	0.8	0.5	0.0	0.2	1.1	0.5	0.0	0.2	1.0	0.4	0.6	1.0
27	1.0	0.1	0.2	0.1	1.0	0.2	0.1	0.3	1.1	0.2	0.9	0.6
28	0.9	0.3	1.0	0.4	0.7	0.4	1.1	0.1	1.0	0.0	1.0	0.1
29	0.4	0.9	0.5	0.6	0.7	0.1	1.0	0.0	0.9	0.0	0.7	0.2
30	0.1		0.3	0.9	0.5	1.0	0.5	0.5	0.2	0.8	0.5	0.4
31	0.3		0.2		0.2		0.2	0.9		1.4		0.5
Mean	0.68	0.66	0.55	0.57	0.70	0.53	0.52	0.49	0.60	0.58	0.60	0.53

Mean for 1888: 0.58

Day	Year 1889											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.5	0.1	1.2	0.7	0.1	0.6	1.0	0.9	0.1	0.1	1.9	0.4
2	0.6	0.0	0.4	0.7	0.0	0.3	0.9	0.7	0.3	0.2	1.3	0.5
3	0.0	0.9	0.2	1.0	0.2	0.2	0.6	0.1	0.1	0.7	0.9	0.5
4	0.1	0.2	0.3	0.3	0.9	0.1	0.1	0.1	0.1	0.2	0.7	0.2
5	0.0	0.1	0.4	0.1	0.9	0.0	0.6	0.0	0.0	1.2	0.7	0.1
6	0.2	0.5	1.6	0.0	0.3	0.1	0.9	0.0	0.1	1.2	0.2	1.1
7	0.8	0.7	1.0	1.0	0.6	0.0	0.6	0.1	0.3	1.0	0.2	0.7
8	0.3	0.7	0.6	1.5	0.1	0.1	0.1	0.5	1.0	0.7	0.0	0.5
9	0.2	0.1	0.1	0.9	0.1	0.9	0.0	0.3	1.7	0.4	0.7	0.4
10	0.8	0.1	0.0	0.5	0.5	0.6	0.0	0.3	1.4	0.2	0.6	0.1
11	0.8	0.0	0.0	0.2	0.1	0.1	0.5	0.5	1.1	0.0	0.4	0.0
12	0.8	0.0	0.4	0.2	0.4	0.0	0.1	0.6	0.7	0.0	0.1	0.0
13	0.7	0.1	0.8	0.4	0.7	0.7	0.1	1.4	0.4	0.6	0.0	0.3
14	0.1	0.6	0.9	0.2	0.3	1.1	0.2	0.4	0.0	0.6	0.1	0.4
15	0.1	0.6	0.5	0.1	0.1	0.4	0.1	0.8	0.1	0.8	0.4	0.2
16	0.0	0.6	0.4	0.0	0.1	0.2	0.1	0.7	0.3	0.3	0.4	0.3
17	0.1	1.1	1.0	0.1	0.1	0.1	1.9	0.2	0.3	0.2	1.1	0.3
18	0.0	1.0	0.6	0.2	0.1	0.0	0.9	0.1	0.6	0.9	0.9	0.1
19	0.1	0.7	0.2	0.2	0.4	0.0	0.9	0.1	0.4	0.9	0.2	0.5
20	1.4	0.7	0.3	0.1	0.2	0.4	0.5	1.0	0.1	1.3	0.0	0.8
21	1.2	0.2	0.4	0.4	0.3	1.0	0.5	0.7	0.4	1.0	0.3	0.6
22	0.8	0.3	0.9	0.4	0.9	0.9	0.0	0.3	1.6	0.8	0.6	0.7
23	0.4	0.4	0.5	0.6	0.1	0.5	0.1	0.3	1.3	0.4	0.1	0.6
24	0.1	0.2	0.6	0.2	0.4	0.1	0.6	0.2	1.1	0.1	0.6	0.2
25	0.2	0.1	0.3	1.0	0.1	0.1	0.6	0.9	0.9	0.1	0.8	0.2
26	0.1	0.3	0.6	0.8	1.3	0.0	0.3	1.3	0.7	0.2	1.4	0.4
27	0.0	0.8	0.6	0.5	0.7	0.0	0.2	1.0	0.4	0.1	1.3	1.0
28	0.1	0.5	1.4	0.9	0.4	0.9	0.5	0.9	0.0	0.4	1.8	0.6
29	0.2		0.9	0.4	0.1	0.2	0.7	0.8	0.3	0.1	1.0	0.6
30	0.4		0.8	0.4	0.5	0.1	0.7	0.6	0.1	0.1	0.9	0.6
31	0.1		0.3		0.8		0.8	0.2		0.3		0.2
Mean	0.36	0.41	0.62	0.47	0.38	0.32	0.49	0.51	0.53	0.49	0.65	0.42

Mean for 1889: 0.47

University of Göttingen,
Göttingen, Germany, December, 1946

THE VEHICULAR ODOGRAPH

By A. G. McNish and Bryant Tuckerman

Abstract—A description is given of the vehicular odograph, a device for automatically plotting the course of a vehicle in which the odograph is mounted. The odograph derives information on direction from a magnetic compass which is read by a photoelectric system and information on distance from a shaft geared to the speedometer-cable. Errors in maps obtained with the device amount to two or three per cent of the total distance traveled under ordinary rough conditions of operation, but with the exercise of certain precautions these errors can be greatly reduced. Detailed discussion on the operation and compensation of a magnetic compass in a vehicle, with particular emphasis on problems of sub-permanent magnetization is included, together with a theoretical analysis of the integrating process employed which involves averaging of discrete intervals.

Cooperation in project—The device described in this paper resulted from an extensive cooperative effort involving (1) the Office Chief of Engineers of the Engineer Board, Corps of Engineers, which set up the requirement, (2) the Department of Terrestrial Magnetism of the Carnegie Institution of Washington which undertook the original design, and (3) the Monroe Calculating Machine Company and the International Business Machines Corporation which put the original development into suitable form for mass production and produced the instruments for Army use. The concept of having a device of this type for military use was put forward in an article in *The Infantry Journal* by W. S. Everett, now Colonel in the Corps of Engineers, who was attached to the Engineer Board when the project was started. Upon his separation from the Engineer Board, the Board's interests were handled by the late Major George A. Rote and Captain D. J. Faustman. The project was proposed to the Department of Terrestrial Magnetism by P. C. Putnam of the Office of Scientific Research and Development which made a first contract with the Carnegie Institution of Washington that the latter's Department of Terrestrial Magnetism undertake the work. Most of the basic ideas in the device were formulated by the writers; during the earlier developments extensive assistance was received from other members of the Department's staff, namely: V. L. Agy; J. M. Barry; J. L. Dalke; R. J. Duffin; and W. F. Wright. The entire developmental program was carried out under the directorship of J. A. Fleming. Upon completion of a workable experimental model assistance was sought from the engineers of the Monroe Calculating Machine Company and the International Business Machines Corporation who extensively redesigned the instrument and added many auxiliary features. Valuable assistance was received from the instrument-shop of the Department under W. F. Steiner.

General remarks—The general purpose of the odograph was to supply a device for military use which, when installed in a vehicle, would give a detailed map of the course taken by that vehicle. It is not our province to set forth the military application of this device; however, it can be left to

one's imagination to supply those details. It may be stated that a large number of these devices were in use by our armed forces in the various theaters of operation. They are finding even more extensive application in peace times.

In order to perform the function set forth two kinds of information are necessary—the instantaneous direction in which the vehicle is traveling and the distance it travels in that direction. This information must be combined and automatically recorded upon a map.

Various devices have been proposed from time to time and there are many files in the Patent Office concerning inventions which purport to do what the odograph does. As far as we know, however, this is the first time that a satisfactory fully automatic mapping device for vehicles has ever been developed. Most of the patent disclosures on mapping devices describe a machine for performing the analysis of information on direction and distance and then placing the information upon a map. They usually presume to take the direction from a compass or similar device without solving the difficult problem of how the compass or similar device is to operate satisfactorily and how the device is to be read automatically. Most of these devices obtain their measurement of distance in the same manner in which it is obtained in the odograph, namely by means of a coupling to the wheels or transmission of the vehicle through a speedometer-cable.

Description of integrator—The type of mechanism which seemed most likely to fulfill the military requirements involved mechanical step-by-step integration. Ordinary friction-drives of the disc-and-wheel, cone-and-wheel, or sphere-and-wheel types might fail under vibration and might not lend themselves to methods of quantity-production. Furthermore, simplification required that the plotting-mechanism be driven directly by the integrating-mechanism without an intervening torque-amplifier. Such a requirement might impose too great a load on any friction-drive device. Step-by-step integration is positive in its action and also, as demonstrated in the manufacture of simple computing-machines, lends itself to quantity-production. The fact that the present form of the odograph manufactured as standard equipment for the Army is identical in basic features with the original "hay-wire" model speaks well for these early decisions.

In the odograph an auxiliary speedometer-cable rotates two step-gears (see Fig. 1). These step-gears have 30 teeth each but not all of the teeth extend the entire width of each gear. The step-gears are mounted on a common axle and are rotated in opposite directions by means of reversing-gears. A gear of narrow width is mounted on a splined shaft so that it engages the teeth of the step-gear. When this small pick-up gear is positioned along the splined shaft so that it is between the two step-gears, it does not rotate as the step-gears rotate, but when the pick-up gear is moved in one direction or the other it picks up varying numbers of teeth depending

upon its position, so that at the end of either one of the gears it picks up all of the teeth. A Scotch-yoke mechanism is provided for positioning the pick-up gear. A crank-arm engages the Scotch yoke which thus moves the pick-up gear along the step-gears as the crank-arm turns. The distances of the pick-up gear from the center of the space between the two step-gears are proportional to the sine of the angle through which the crank-arm is turned. This crank-arm, by a system to be described later, follows the indications of the compass. A second pick-up gear and Scotch-yoke-crank mechanism is located on the opposite side of the step-gears. The second crank-arm likewise reproduces the indications of the compass but is placed 90° out of phase with the first.

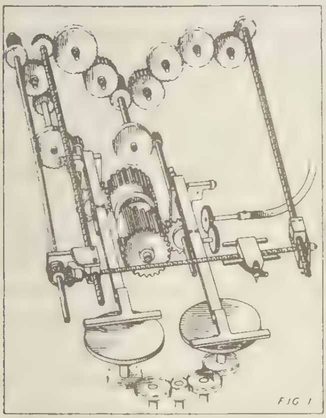


FIG 1

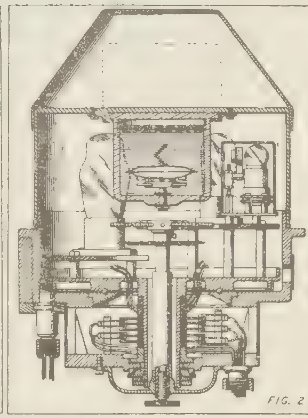


FIG. 2

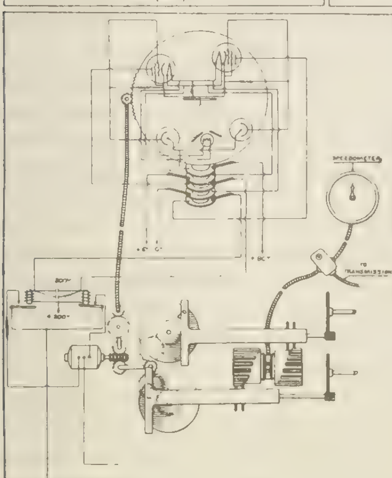


FIG. 1—SCHEMATIC DIAGRAM OF INTEGRATING MECHANISM OF ODOGRAPH

FIG. 2—SCHEMATIC DIAGRAM OF COMPASS USED WITH ODOGRAPH

FIG. 3—COMPASS AND INTEGRATING MECHANISM OF ODOGRAPH IN COMBINATION SHOWING WIRING

As the step-gears are rotated by the speedometer-cable and the crank-arms reproduce the indications of the compass as to the heading of the vehicle, the rotation of the pick-up gears will be proportional to the distance the vehicle has traveled in a north-south direction for one pick-up gear and in an east-west direction for another. These rotations are carried by trains of gears to two lead-screws which move a pencil across a map and thus the pencil describes upon the map the course which the vehicle has followed.

There are changeable reduction-gears interposed between the pick-up gears and the lead-screws so that the integrator can be made to draw to any desired scale by simply turning a lever-arm. Eight basic scales are provided on the present production models, the largest scale being one in 20,000 and the smallest scale being one in 500,000. An intermittent cam-action operating on a principle similar to that employed in the step-gears permits a continuous range of map-scale between these limits. Thus the machine can plot on a scale in 1:50,000 or 1:62,500, which is nearly one inch to a mile, and 1:63,360, which is exactly one inch to a mile. The original experimental model was equipped to plot to one scale only, use of gear-shifts being incorporated in later models.

It may seem that the above method of integration is not capable of high accuracy because there are only 30 teeth on each of the step-gears and hence, apparently, the sine of the angle cannot be divided into finer intervals than 1/30th. However, the mechanism for reproducing the compass-heading is a hunting system, so that a pick-up gear does not always engage the same number of teeth on the step-gear while the vehicle is on a fixed heading. For example, if the vehicle is traveling on a heading on which it is necessary to pick up 10 and 1/4 teeth per revolution to give its true distance traveled in, say, an east-west direction, the pick-up gear will oscillate between the tenth tooth and eleventh tooth so that on the average it engages ten teeth three times and eleven teeth once, giving an average pick-up of 10 and 1/4 teeth. This device has been found to give a very high degree of accuracy so that in tests in the laboratory the instrument is capable of giving results with errors well under one per cent. A single fault exists in that, if the vehicle is traveling on a heading of approximately 5° from one of the cardinal points, the distance recorded in that direction is 1/2 of 1 per cent too great. This is the maximum error inherent in the system, but the error falls rapidly from this point, being zero on a cardinal heading, and changing sign as the departure from the cardinal heading increases. This will be discussed in detail later.

The compass—The method of following the compass-indications employed in the odograph was particularly developed for this purpose. Incidentally it also supplies an excellent type of remote-reading magnetic compass. It was decided early in the development that a magnetic compass

was the only suitable instrument for this use since there is no gryocompass small and rugged enough for mounting in a vehicle and a directional gyroscope drifts too rapidly to have value in this application.

In reading the magnetic compass it was necessary to do so without imposing any restraint on the action of the magnetic needle. It was also necessary to devise a mechanical arrangement for the compass-card which would give as good magnetic and dynamic performance as possible when used in the vehicle. The simplest and most obvious method was to read the compass photo-electrically. For this purpose a mirror was mounted on the compass-card (see Fig. 2). Light from a small automobile-bulb is passed through a lens and brought upon the mirror on the compass, reflected back to one of two mirrors on either side of the lamp and brought on to the proper one of two photocells. Each of these photocells fires one of a pair of thyratrons connected in a transfer-circuit (see Fig. 3) which control the action of an electromagnetic reversing-clutch. (In the experimental model a pair of relays was used to reverse the rotation of an electric motor instead of the electromagnetic reversing-clutch, but electronically the two systems are identical.) The entire electrical and optical system is mounted on a turntable about the compass-bowl and is connected through a flexible cable to the shaft bearing the clutches. Electrical connections to the turntable through a set of brushes and slip-rings connect it to the power-supply and to the clutches in the integrator.

When suitable voltages are applied to the compass, the lamp is lit and one of the thyratrons automatically fires. This energizes the electromagnet and engages the clutch which causes the shaft of the compass to rotate which in turn moves the turntable around until light reflected from the compass falls upon the photocell controlling the other thyratron. This fires the second thyratron and the clutch-mechanism is reversed through its electromagnetic control, which starts the shaft rotating in the opposite direction. Firing of the second thyratron extinguishes the first one, which is now ready for another operation. As the turntable is rotated, light falls upon the photocell controlling the first thyratron, which in firing extinguishes the second thyratron and again reverses the rotation. This process continues as long as the odograph is in operation, the follow-up mechanism continually oscillating through an angle of about 10°. The crank-arms which position the pick-up gears are connected to the rotating shaft so that they also partake of the motion of the compass following-system.

In addition to producing an averaging-effect in the integrating-mechanism, this hunting-system has several advantages. It faithfully reproduces the average position of the magnetic compass. Back-lash in the gears or in the shafts becomes of no consequence so that close tolerances in construction are not necessary. By use of the symmetrical system, variations in voltages from the battery and so forth do not change the average position

of hunting but only cause variations in the angle of hunt which is of minor importance to the mechanism provided it stays within reasonable bounds. The thyratron-circuit employed here is a "memory-circuit," that is, if the compass were to be suddenly disturbed by a rapid turn or bounce of the vehicle so that the light passed completely beyond the photocell, the circuits would "remember" on which side the light went off and produce the proper rotation to correct for the effect.

Power for operation of the electronic circuit is supplied by a vibrator-transformer circuit such as is employed in automobile-radios. To avoid the magnetic effects of heavy direct currents near the compass, alternating current from the vibrator is used for heater-currents in thyratrons and to light the lamp. In the experimental model and the pilot models conventional vibrator-packs, modified for the purpose, were employed. Specially designed General Electric power-packs were developed for the production models which included voltage-regulation for the heating and lighting current. This change, the use of a voltage-regulator tube for the photocell-supply, and the use of electromagnetic clutches instead of a reversing electric motor were the only essential electric changes in the production models as compared with the experimental models.

Some attention should be given to the compass-card employed. It would not be suitable to use a double-pivoted compass in the odograph because any tilt of the vehicle would subject the compass to the effect of the Earth's vertical field and produce errors in its readings. On the other hand, a single-pivoted compass, subjected to violent accelerations, departs from horizontality. This would tilt an ordinary mirror and throw the beam of light up or down so that it would not fall upon the photocells. This fault has been averted by use of a right-angled mirror so that no matter how much the compass tilts, up to an angle of 45°, the beam is returned horizontally. The compass is damped by a special oil, the viscosity of which does not change greatly with temperature. An expansion-chamber and bubble-trap in the top allow for thermal expansion.

Compensation of the compass—Operation of a magnetic compass in a steel and iron vehicle poses a problem in itself. Not only does the vehicle have a permanent magnetic field of its own to cause deviations of the compass but it also has induced magnetic fields depending upon its heading in the magnetic field of the Earth, and, worst of all, the vehicle has what has been called sub-permanent magnetism, that is, magnetism which it acquires when going over a bump in one direction and which it may or may not lose on going over a bump in another direction. These effects, however, have been reduced to a minimum so that under reasonably favorable conditions the accuracy of the compass is better than 1° on all headings.

Compensation of a magnetic compass, as all magneticians know, is an old problem with a classical solution. It is a homeopathic treatment in that

effects of permanent magnetism are eliminated by introduction of permanent magnets near the compass and effects of induction are eliminated by appropriate disposition of soft iron about the compass. The permanent-magnet corrector-system is mounted above the compass in the odograph and consists of two pairs of short bar-magnets, each pair being rotated by gears. The two magnets making up one pair are mounted on shafts bearing the gears which engage each other so that when one shaft is rotated the other shaft rotates in the opposite direction. In the position producing maximum correction the magnets are parallel, both north poles being in the same direction. When the shafts are rotated through 180°, the magnets have their north poles in the reversed direction, thus creating a reversed field at the compass. In passing through the 90°-position the magnets are so directed that like poles are in opposite directions, producing zero-field at the compass. One pair of magnets corrects for longitudinal magnetism and the other for transverse magnetism. The actual corrector-system employed in the production compass was taken from a standard aircraft-compass; in fact, the parts used in the production model were obtained from the manufacturer of that particular aircraft-compass.

It was also necessary to provide a similar corrector for the vertical magnetism of the vehicle which acts upon the compass when the vehicle is not on level ground. The system employed was the one designed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (DTM CIW) for use with tank-compasses.

Soft-iron correction is supplied by means of a segmented permalloy rod immediately beneath the compass which is variable in length and distance from the compass and can be arranged in any one of four directions. This system was developed for the tank-compass and differs in action from the conventional iron spheres commonly found on marine compasses. It has only one advantage over the sphere-correctors, namely, that it is much more compact. It derives its corrective action not from induction in the Earth's field but from induction in the field of the compass-needles themselves so that erroneous readings of the compass due to soft iron in the vehicle are corrected by the action of the magnetic needle.

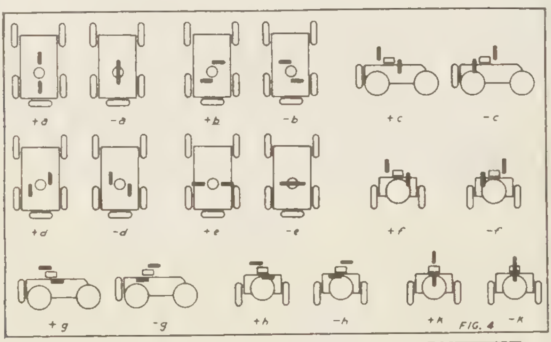
Some aspects of the behavior and the compensation of the compass merit special consideration. These will be made clearer by setting forth the classical treatment of compass-deviations as originated by Poisson. Following the procedure and symbolism set forth in the British Admiralty compass manuals the equations for the forces acting on the compass may be written

$$X' = X + aX + bY + cZ + P$$

$$Y' = Y + dX + eY + fZ + Q$$

$$Z' = Z + gX + hY + kZ + R$$

in which X', Y', and Z' are the components of magnetic force at the compass-position directed forward, to the right, and downward with respect to the vehicle; X, Y, and Z are the corresponding components of the Earth's magnetic field (if the vehicle is non-magnetic $X' = X$, etc.); P, Q, and R are the corresponding components of permanent magnetism of the vehicle; and a, b, $\cdots$ k are the coefficients of induction in the soft iron of the vehicle by the Earth's field (thus bY is the contribution to longitudinal magnetic force caused by induction due to the component of the Earth's magnetic field transverse to the vehicle). The coefficients a, b, $\cdots$ k may assume either positive or negative values. Their effects may be represented as due to nine pairs of equivalent soft-iron rods disposed as shown in Figure 4. It will be noted the effects of the rods a, e, and k may be positive or negative according as the ends of a pair nearest the compass are separated or adjacent; also that the positive effects will occur if only one of the separated rods a, e, or k is present.



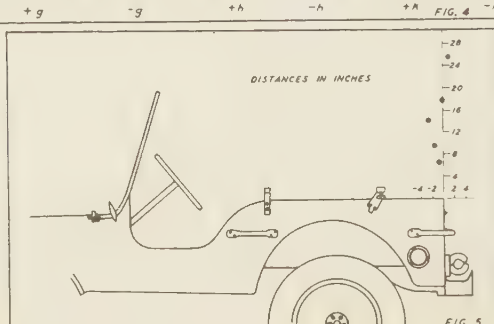


FIG. 4—DIAGRAMMATIC REPRESENTATION OF INDUCTION-COEFFICIENTS OF A VEHICLE

FIG. 5—POSITIONS ABOVE TAIL-PANEL OF 1/4-TON JEEP WHERE SUB-PERMANENT LONGITUDINAL EFFECTS ARE ZERO

The deviations of the compass, δ, are given by

$$\sin \delta = \overline{A} \cos \delta + \overline{B} \sin \xi' + \overline{C} \cos \xi' + \overline{D} \sin (2\xi' + \delta) + \overline{E} \cos (2\xi' + \delta)$$

in which ξ' is the heading of the vehicle according to the compass and

$$\overline{A} = (1/\lambda)(d - b)/2$$

$$\overline{B} = (1/\lambda)(c \tan \theta + P/H)$$

$$\overline{C} = (1/\lambda)(f \tan \theta + Q/H)$$

$$\overline{D} = (1/\lambda)(a - e)/2$$

$$\overline{E} = (1/\lambda)(d + b)/2$$

H being the horizontal component and θ the angle of dip of the Earth's magnetic field, and λ being given by $[1 + (a + e)/2]$, or H'/H, that is, the ratio of the average directive force in the compass-position on all headings to the Earth's horizontal force. The terms involving ξ' are referred to as the semi-circular deviations and the terms involving $2\xi'$ are referred to as the quadrantal deviations. Since the development of the above equation is well known, it will not be repeated here.

The effect of the bar used for compensating quadrantal deviation in the odograph-compass bar is to produce a term in the equation for deviation of the compass of the form $\overline{D}' \sin (2\xi)$ [as compared with $\overline{D} \sin (2\xi' + \delta)$ as given above]. The coefficient $\overline{D}'$ has approximately the value KM/Hr^6 in which K is the coefficient of induction of the bar, M the magnetic moment of the compass, and r the distance of the bar from the magnet-system. Since δ is kept negligibly small, the effect of the permalloy rod may be adjusted to exactly neutralize the term containing $\overline{D}$ due to soft iron in the vehicle since D' may be made either positive or negative by placing the bar either longitudinal or transverse. The term containing $\overline{E}$ (if present) is compensated by placing a similar bar at the same distance but placed diagonally with respect to the coordinate-system of the vehicle. This bar produces a term $\overline{E}' \cos (2\xi')$.

This method of correcting the quadrantal deviations possesses one advantage over conventional methods of correction in that it constitutes a more compact system. It is subject to three faults, namely, its correction is not invariant with magnetic latitude, it magnifies errors from other sources if the quadrantal deviation is very large, and it does not auto-

matically correct for certain terms in the heeling-error and pitching-error. (In most cases, however, the method of correction of marine compasses involves so much induction in the spheres that they behave in part as induction-bars and are subject to these same faults.) Correction for changes in latitude are accomplished with the induction-bars by varying their distance from the compass, facilities for which are provided in the odograph-compass.

No provision is made to correct for the second fault, but, inasmuch as performance of the odograph depends on keeping δ negligibly small, the difference between $(2\xi' + \delta)$ and $2\xi'$ is of small consequence. This significance may be best apprehended by writing the equation for deviations of the compass including the terms containing $\bar{B}'$, $\bar{C}'$, $\bar{D}'$, and $\bar{E}'$ which correct completely the terms $\bar{B}$, $\bar{C}$, D, and E. Then if δ assumes any value other than zero, say, by a change in $\bar{B}'$ or $\bar{C}'$, the change in δ is given by

$$d\delta/d\bar{B}' = -\sin\xi'/(1 - \bar{D}\cos 2\xi' + \bar{E}\sin 2\xi')$$

and

$$d\delta/d\bar{C}' = \cos\xi'/(1 - \bar{D}\cos 2\xi' + \bar{E}\sin 2\xi')$$

These relationships may be compared with $d\delta/d\bar{B}' = -\sin\xi'$ and $d\delta/d\bar{C}' = \cos\xi'$ for the classical system of quadrantal compensation. If the quadrantal deviation amounts to 20°, an extremely large value, the value of δ is increased by 50 per cent in the worst case over what it would be if the conventional (and assumedly perfect) system were used. In general, the attempt is made to avoid large values of quadrantal deviation by selection of an appropriate location for the compass.

The third fault may best be understood after considering general heeling-errors and pitching-errors as given in the next paragraphs.

Deviations due to heeling and pitching—The equation given previously for deviations of the compass assumes implicitly that the vehicle is on a level surface. If the vehicle is tilted, other terms affect the deviations, in particular the term R. This is known as heeling-error. These effects have been found to be very great in some cases. The deviation of the compass produced by tilting the vehicle may amount to as much as 3° for each degree of tilt under certain rare circumstances. A correction for this effect is provided in the odograph-compass by a magnet-system similar to that used for the semi-circular correctors which produces a vertical field at the compass to neutralize the effect produced by the term R in the original equations. The importance of this tilting-effect must be stressed. Thus driving north and returning south on a high-crowned road can produce errors of closure of several per cent with an otherwise perfectly compensated compass if no correction is made for the so-called heeling-error.

Actually an appreciable part of the heeling-error is usually due to

induction in the soft iron of the vehicle, the principal term, the heeling-coefficient being given by $J = [1/\lambda][(e - k) \tan \theta - R/H]$, where J is the deviation of the compass in degrees produced by 1° of heel. This term is the error introduced in the deviations when the vehicle is tilted to left or right when headed in a northerly or southerly direction. For any given installation the values of e, k, R, and λ are constant, and if the vehicle does not change its geographical position appreciably the values of θ and H may be regarded as constant. Thus the correction of heeling-error by permanent magnets as previously described is entirely satisfactory, and no change in setting of the heeling-correctors is necessary unless the vehicle moves to a new locality or undergoes some major structural modification.

In marine installations only heeling-error, not pitching-error, is conventionally considered. But pitching-error is of considerable importance in vehicles which may travel great distances up or down a grade. Pitching-error occurs when the vehicle is on a grade headed in an easterly or westerly direction, pitching-error and heeling-error thus being out of phase by 90° The principal term of the pitching-coefficient is given by $I = [1/\lambda][(a - k) \tan \theta - R/H]$, similar to the heeling-coefficient.

The difference between the heeling-coefficient and the pitching-coefficient is given by $(J - I) = [1/\lambda][(a - e) \tan \theta] = 2D \tan \theta$, for the classical conditions. If the quadrantal coefficient D is corrected by spheres in which there is no induction from the magnets of the compass, the expression $(a - e)$ is zero and the coefficients of heeling and pitching are equal, and hence both are correctable to zero by the heeling-correctors. The method of correcting D in the odograph-compass does not do so by reducing $(a - e)$ to zero but by substituting another effect to neutralize the quadrantal deviations. Therefore, it may not always be possible to reduce both the heeling-coefficient and the pitching-coefficient to zero. Since in standard installations the compass is placed where the quadrantal deviation is small, this fault is largely of academic interest.

Effects of sub-permanent magnetism—It appears from the foregoing remarks that complete compensation of a magnetic compass so that the deviations are negligible is only a matter of diligence in matching the corrections to the natural deviations. This condition has been frequently accomplished in experiments but in actual practice there are other factors which vitiate the accuracy of the results.

The classical theory of the compass does not take into account the so-called sub-permanent magnetic effects. The soft iron in a vehicle does not lose all the magnetization acquired on one heading when turning to another, particularly when the vehicle has been subjected to a severe shock on that heading. As these shocks are unpredictable, no simple arrangement can be made for counteracting their effects, but, by selection of the most suitable position for the compass, the effects can be minimized.

The vertical soft iron of the vehicle, corresponding to the rods *c*, *f*, and *k*, being always in the vertical field of the Earth, are not subjected to magnetic fields which vary with heading of the vehicle, appreciable variations in the field to which they are subjected being experienced only when the geographic region in which the vehicle operates changes considerably. Furthermore, if the compass is symmetrically mounted with respect to the horizontally disposed soft iron, only effects corresponding to the rods *a* and *e* need be considered.

If the rods *a* and *e* behave purely as soft iron, no fields tending to deviate the compass from north will be produced when the vehicle is headed north or south, for then the field produced by the rods *a* will be parallel with the Earth's field while the rods *e*, being perpendicular to the Earth's field, will not be magnetized and hence will produce no field. Similar conditions apply if the vehicle is headed east or west, the rods *a* then losing their magnetism and the rods *e* having their fields directed parallel with the Earth's field. However, on intermediate headings the rods *a* and *e* are both magnetized with intensities proportional to the cosines of the angles they form respectively with the Earth's field, and their fields act on the compass with forces proportional to the sines of the angles between their respective directions and the direction the compass is pointing. In general, this behavior of soft iron is realized in practice provided the vehicle is subjected to no violent shocks.

If the vehicle suffers a severe shock while heading north or south, however, the rods *a* will acquire a greater and more permanent magnetization than that due to normal induction. This magnetization will not be entirely lost when the vehicle changes its heading unless it is subjected to exactly the corrective amount of shock on another appropriate heading. This sub-permanent magnetization which the rods *a* have acquired appears as a change in the more truly permanent magnetism of the vehicle designated by *P*.

It will be noted by reference to Figure 4 that the effects of the rods *a* are positive if the compass is between the pair (or at the end of one rod if there is only one) or negative if the compass is over or beneath the rods. Between these two locations there must be a location of zero-effect where the transition from positive to negative effects occurs. If the compass is placed in this position it will not be subject to changes in sub-permanent longitudinal magnetism of the vehicle, and, since deviations when heading east or west are affected only by longitudinal magnetism, these deviations will remain unchanged regardless of the shocks to which the vehicle is subjected.

Likewise a location may be found where the effects of the rods *e* are zero. In this case the deviations with the vehicle heading north or south would not be affected by shocks on any heading. Generally, no location can be found at which compensation of the compass is free from changes due

to shocks incurred on headings of north and south and also on headings of east or west. The most satisfactory solution is to eliminate the maximum effect, and, if possible, so modify the vehicle that the lesser effect is minimized. In general, effects of the rods a are greater than the effects of the rods e; thus the compass may be placed in the best location in the median plane of the vehicle and offending transverse iron members of the vehicle replaced by non-magnetic material. In the perfect case this would eliminate all changes in deviation due to sub-permanent magnetism.

In the foregoing the assumption is made that the soft iron giving rise to the quadrantal deviations is the same iron which gives rise to the sub-permanent effects. This may not always be true so that the best procedure for eliminating sub-permanent effects must be decided by experiment. In a following section the actual experiments conducted to reduce the effects of sub-permanent magnetism will be described.

The compass in the first installation in a Jeep was placed about eight inches above the floor in the median plane of the vehicle just to the rear of the front seats. Magnetic measurements made later suggested a better position about three feet above the floor and about one foot forward of the tail-board. This position, although far superior to the original, did not eliminate all of the semi-circular change which was still of the order of 5° to 10° under extreme shock.

In order to investigate means of improving compass-performance, an odograph was installed in a Jeep and testing begun. In the preliminary work the compass was in a position somewhat higher and farther forward than that suggested by the work done previously. The tests consisted of hammering various parts of the body of the Jeep while the vehicle was on different headings and of running the vehicle over a short, bumpy course laid out on cardinal headings. The bumps consisted of logs, half imbedded in the ground, perpendicular to the direction of travel. Other compass-positions, different as to height and fore-and-aft location, were tried. The same general technique was followed for each position.

In general, it can be said that hammering or cross-country running on any cardinal heading will produce a change in compensation on the cardinal headings at right-angles to this heading, that is, hammering the vehicle while headed east or west will cause a change in the semi-circular error on north and south (designated by the coefficient C), and vice versa. Moreover, the change produced by pounding on one heading is in the opposite direction to the change produced by pounding on the opposite heading. For example, if pounding on an east heading throws the north-south compensation out to the west (giving negative C), then pounding on a west heading will throw the north-south compensation out to the east (giving positive C). For the early part of the work, the top, the spare wheel, and the spare tire were removed.

The amount by which the compensation is thrown off with the vehicle on a particular heading depends on the severity and the number of shocks to which the vehicle is subjected. Since the severity of the jolts received usually depends on the speed of the vehicle (for given terrain), the change in compensation must also depend on the speed. There is, however, a "saturation"-effect in the iron of the vehicle which allows the change in semi-circular compensation to reach, but not to exceed, a certain maximum value. Once this maximum change has been produced by rough travel on a heading, further rough travel will not increase the change.

For any given terrain of fairly uniform roughness, there is a "safe speed" below which no change in compensation is produced. This "safe speed", of course, will be low for rough terrain and will be higher for smoother travel. At first, as the speed increases the change increases until, for some particular speed, the maximum mentioned above has been reached. But if the speed be increased beyond this point where the maximum obtains, a skimming effect may be noticed which results in a smaller change in compensation than is produced at somewhat lower speeds. This is due to the fact that on this particular course (as in cross-country travel) the speed may be so high that the wheels of the vehicle have no time to drop into the holes in the course and the resulting shocks are less severe.

The data for the change of compensation as a function of speed were obtained by running the relatively short rough test-courses at various speeds and finding the change produced by each rough run.

A good compass-position should be sought when a compass is to be installed in a vehicle. Ordinarily this means a position which puts the compass far enough away from the iron of the vehicle that the original compensation is easily effected and such that the sub-permanent magnetism in this iron will not produce an appreciable change in magnetic field at the compass. If this reasoning be followed closely, however, the resulting (ideal) position would be outside the vehicle, above or to the rear by a distance equal, perhaps, to the length of the vehicle, and the compass would then be extremely vulnerable. For this reason and for reasons of convenience a compromise position is usually found which will ordinarily not prevent some change in semi-circular compensation from occurring.

The horizontal field produced by a horizontal magnet is zero along each of two symmetrically located curves in a vertical plane through the magnet. The location of these curves depends only on the location of the magnet (still considered horizontal) and not on the strength of the magnet. If the magnet changes only in strength, the location and shape of the curves do not change and the horizontal intensity along these curves will remain equal to zero. If the longitudinal semi-soft iron of the vehicle be thought of as such a magnet (whose strength may change but whose location does not) there should be compass-positions which will not allow changes in

compensation to occur when the vehicle is headed east or west (coefficient B). The maximum change in B was obtained for each of several compass-positions on each of a number of levels. The amount and the direction of change is zero for one point at each level. These zero-positions, relative to the tail-panel of the Jeep, are plotted in Figure 5. At all of the levels used, the compass was approximately centered over the tail-board in order that the change in B should be zero.

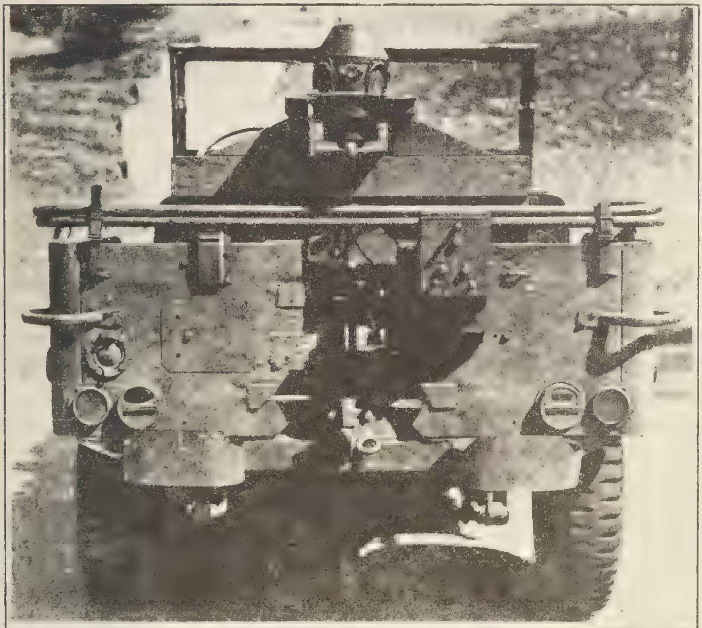


FIG. 6—INSTALLATION OF COMPASS IN 1/4-TON JEEP FOR STUDY OF SUB-PERMANENT MAGNETIC EFFECTS, REAR VIEW, SPARE TIRE REMOVED, SHOWING WOODEN BLOCK FOR MOUNTING SPARE TIRE

Positioning of the compass as described above can eliminate only one component, B, of the changing semi-circular error. To reduce changes in the other coefficient, C, alterations were made in the magnetic condition of the vehicle. Preliminary work done in the laboratory at DTM CIW showed that the magnetic field over the middle of a vertical steel-plate could be materially reduced—actually made negligible—at a particular height by a vertical cut or by an inverted V-cut. The position where the field was zero was found to be lower for the inverted V-cut. This modification was made on the tail-board of the Jeep. Also, in order to break the magnetic circuit still allowed by this cut, the floor was split down its middle by about half its length.

Changes in C were reduced somewhat by these modifications—further improvement being obtained by cutting out entirely part of the tail-board of the Jeep. Change in C was thereby reduced from about $\pm 5°$ to about $\pm 2°$. Stability of compensation on the other cardinal heads remained unaltered.

This change in the magnetic condition of the Jeep was expected to give even greater improvement, but the back of the vehicle is actually responsible for only a part of the change in compensation experienced on rough travel. This is demonstrated by the fact that, whereas the sign of the change is not reversed (by the cuts mentioned) for rough travel, the sign of the change in compensation is reversed if the back is pounded with the vehicle headed east or west. The Jeep as modified for these tests is shown in Figure 6. The large support for the compass was built to permit shifting this unit to various positions.

Since the present standard position of the spare wheel and tire cannot be altered easily, the exact effect of the spare in its present position was next studied. With the spare mounted, change in C increased only slightly, but the position for zero-change of B was then found a good bit farther to the rear. Obviously it is not desirable to mount the compass in such a position that it is completely outside the vehicle or that it interferes with the possible removal of the spare. Therefore, magnetic insulation of the spare from the body of the Jeep was tried. A wooden block was substituted for the steel-bracket normally holding the spare and the effect on change in B was considerably reduced. The zero-position was found to be only slightly rear of the zero-position found originally.

Results achieved by these various modifications are shown in Table 1. It will be noted that under the optimum conditions no changes in compensation with the vehicle headed east or west can be produced by rough driving, and that changes in compensation with the vehicle headed north

Table 1—*Maximum changes in compensation due to rough driving*

Conditions	Changes in compensation	
	E-W (B)	N-S (C)
	°	°
Compass in standard position	$\pm$1-1/4	$\pm$3-1/4
Compass in "zero" position		
Spare tire off, bows in place	0	$\pm$3
Spare tire off, bows off	0	$\pm$2-1/2
Spare tire in place, bows off, body split	0	$\pm$2-3/4
Spare tire off, bows off, body split	0	$\pm$2
Spare tire on wood block, bows off, body split	0	$\pm$2-1/4
Spare tire on wood block, bows on, body split	0	$\pm$2-1/2

or south amount to only 2°. In practical terms this means that, in the extreme case, if the vehicle suffers severe shock while heading east or west and then is driven over a smooth road entirely to north or south, the error due to change in compensation will amount to only three per cent. This is the worst condition and will be rarely experienced in practice. No errors would result while traveling east or west, and if the above-mentioned road to north or south were rough, part of the sub-permanent effect would be shaken out in traversing it and the error would thereby be reduced.

Mechanical effects of vibration on deviations of the compass—In the original odograph, vibrations set up in the vehicle while traveling cross-country and over very rough roads caused deviations of the compass entirely independent of the effects of the magnetic changes and constituted a serious limitation on the usefulness of the odograph. On moderately smooth roads such vibrations were not severe enough to produce appreciable errors but on corduroy-roads the effects became very severe.

Attempts had been made to eliminate effects of vibration in early installations of odographs in military vehicles by mounting the compass on anti-vibration mounts. These mounts are of such nature that they will insulate the compass against certain frequencies but accentuate the effects at other frequencies in normal rough driving, particularly on striking individual bumps. The vibrations of the vehicle cover a more or less continuous range of frequencies so that insulation against shock and vibration by use of anti-vibration mounts is not effective. It was found more satisfactory to use no anti-vibration mounts at all but to fix the compass to the vehicle as rigidly as possible. In practically all cases this gave the most satisfactory performance. By driving the vehicle so as to avoid critical speeds, good results were obtained.

After the basic requirements of performance of the odograph had been met and the device had been found to be suitable for general military use, investigations of vibrational effects on compasses in general were undertaken. It was fairly obvious from these studies that a liquid-damped compass subjected to circular vibratory rotation in a horizontal plane is deviated from a correct reading by hydrodynamic forces. If the liquid and the container of the compass without the compass-card being mounted are subjected to this type of vibration, no rotation of the liquid occurs. Therefore, by coupling the compass-card to the liquid in such a way that the card partakes completely of the motion of the fluid, vibrational deviations should be eliminated.

Experiments in this direction were tried by placing vertical surfaces on the compass-card tending to make it move with the liquid and by buoying the major part of the weight of the card by means of a float-chamber, thus making the compass have almost the same density as the liquid in which it is mounted. Compass-cards involving this new design were made

and subjected to tests in the laboratory and on highways. Figure 7 shows comparative records obtained on a rough corduroy-road with the old-type compass-card and with the new-type compass-card. It may be noted that the new-type compass-card gives almost equally faithful reproduction of the course regardless of speed.

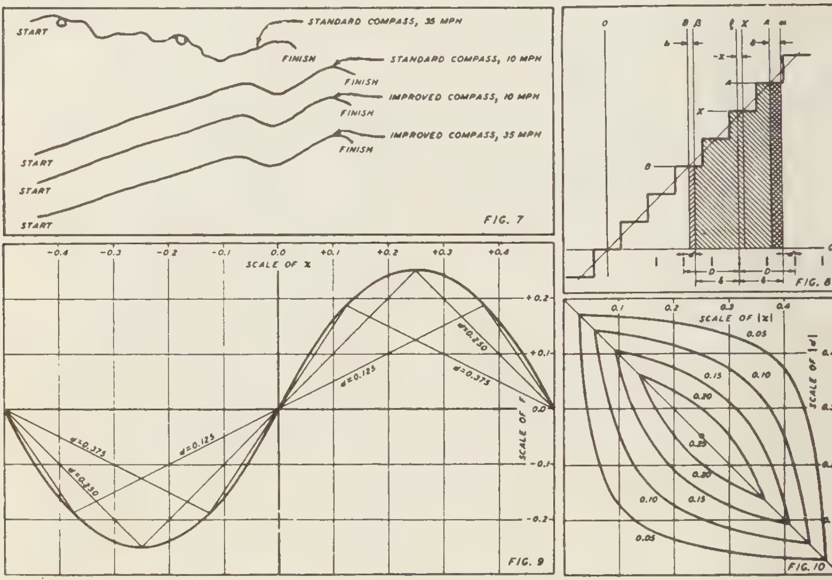


FIG. 7—ODOGRAPH-RECORDS OF IDENTICAL 1.6-MILE RUNS OVER ROUGH-CORDUROY ROAD AT VARIOUS SPEEDS SHOWING EFFECTS OF VIBRATION ON STANDARD AND ON IMPROVED COMPASS-CARD

FIG. 8—DIAGRAM ILLUSTRATING THEORY OF LINEAR HUNTING, AND DEPENDENCE OF NUMBER OF TEETH PICKED UP ON THE POSITION OF PICK-UP GEAR

FIG. 9—THE DEPENDENCE OF ERROR-FUNCTION, F, ON x (FRACTIONAL PART OF NUMBER OF TEETH IN INTEGRAND) FOR VARIOUS VALUES OF d (FRACTIONAL PART OF HALF-ANGLE OF HUNT) WITH LOCUS OF VERTICES OF THESE GRAPHS

FIG. 10—CONTOURS OF ERROR-FUNCTION, F, IN TERMS OF x AND d (FRACTIONAL PARTS OF INTEGRAND AND HALF-ANGLE OF HUNT, RESPECTIVELY)

Effect of "hunting" on the accuracy of the odograph—The design of the compass and the integrator in the odograph is such that the system oscillates or "hunts" about a mean position which is taken as the correct magnetic heading. This hunting is greatest at the integrator, where the driving power is applied, and is somewhat reduced at the compass by backlash, especially in the phosphor-bronze flexible cable.

This hunting was designed into the odograph for three reasons. It eliminates the dead space which would obtain in a system not continuously adjusting. It minimizes errors due to backlash, since they are taken up alternately in each direction. Also it provides a more accurate method of integration than otherwise obtainable with the system of a finite number of teeth.

The problem of accuracy of integration is as follows: If the vehicle is traveling so that its course makes an angle ξ with the magnetic meridian, the distance traveled to the north is given by $\xi_n = L \cos \xi$ and the distance traveled to the east is given by $\xi_e = L \sin \xi$, L being the distance the vehicle travels. If a theoretically perfect method of integration were used, the stylus of the odograph would move distances on the map paper proportional to ξ_n and ξ_e. For reasons previously stated, a theoretically perfect system of integration was not used and a step-system was substituted. How closely the distances north and south, and east and west, indicated by the odograph agree with the true values is investigated in the following development. For this purpose, only one of the components of motion, that is, north-south or east-west, need be investigated since the two components are independent.

The step-gears of the odograph have 30 teeth. Evidently, in the absence of hunting, the error in integration could be as large as one-half tooth per revolution, or a relative error (error divided by arc-length) of $1/2N = 1/60 = 1\ 2/3$ per cent (N being the number of teeth on each gear), if the vehicle continued to travel on a fixed heading. (In actual service the oscillations of the compass have an averaging effect similar to hunting.)

In development of the theory of how hunting affects the accuracy of integration, the following assumptions are made (the action of the odograph is otherwise exact): The vehicle remains on a heading long enough for the averaging to be effective; the hunting is over a fixed angle centered at the correct heading, with equal times spent on equal parts of the range (that is, the graph of angular displacement against time is a saw-tooth). The odograph was designed to approximate this behavior by the use of reversing clutches (low inertia and high torque) instead of reversing motors (high inertia and low torque).

The theory of hunting is greatly complicated by the fact that the hunting is in azimuth, not in the integrand. However, except for the regions where the sine or the cosine, whichever component is being integrated, is approximately unity, we can make the approximation that the integrand is a linear function of the azimuth over the small range covered by the hunting. This is the theory of linear hunting. The deviations from this approximation will be considered later. The theory of the linear hunt is applicable to other integration problems than the odograph.

The operation of the odograph is such that, without hunting, the pick-up gears (for a given component) will pick up the number of teeth nearest to the correct value. This relation is shown by the step-function in Figure 8, where the horizontal distance represents the position of the pick-up gear and the vertical distance represents the number of teeth picked up. For example, if the integrand is ξ (measured in terms of a tooth as unit, like all the numbers in this treatment), then in the absence of hunting the number of teeth picked up will be the nearest integer, or X, represented by the

ordinate X of the step-function at the abscissa ξ. The error is the fraction $x = \xi - X$, and lies between $-1/2$ and $+1/2$.

Suppose the pick-up gear, instead of being at the value ξ, fixed for a given compass-heading, oscillates with uniform speed between two limits, $\alpha = \xi + \delta$ and $\beta = \xi - \delta$, where δ is called the half-width of hunt. Then, for a given revolution of the step-gear, the position of the pick-up gear will be a random value between β and α, and the number of teeth picked up will be the number corresponding to that momentary position. If the periods of oscillation of the pick-up gear and of rotation of the step-gear are incommensurable, then the average number of teeth picked up per revolution will in the long run be equal to the average value of the step-function between the abscissa liimits β and α. (There is no connection between the two periods, and so the assumption of incommensurability is a reasonable one.) This mean value of the step-function is of course the quotient of the area under the step-function between the limits β, α, by the length of the base $(\alpha - \beta)$. The difference between this mean value and the true value ξ is the error of integration, which will be denoted by E. It has been seen that for no hunting, $(\delta = 0)$, $|E|$ may be as great as $1/2$ (tooth). The theory of linear hunting will determine E, as a function of the integrand ξ and the angle of hunt δ, with the object of reducing its magnitude.

It will be advantageous to write each of the quantities ξ, δ, α, β, as the sum of the nearest integer X, D, A, B, and a fraction x, d, a, b, each lying between $-1/2$ and $+1/2$. Then we write

$\xi = X + x$ for the desired value of the function
$\delta = D + d$ for the half-width of hunt
$\alpha = A + a$ for the right end of the hunt
$\beta = B + b$ for the left end of the hunt

as shown in Figure 8. The region under the step-function between β and α is shown as the region with hatching slanting downward to the right. Its area is found by considering it as the algebraic sum of three areas. Two of these (shown hatched downward to the left) are the rectangles under the steps between β and B and between A and α. The third region under the step-function, between B and A, is readily seen to be equal in area to the region under the slant line between the same limits. Thus the area under the step-function between β and α is equal to

$$-Bb + Aa + (A - B)(A + B)/2$$

The mean ordinate of the step-function between the abscissas β, α is this area divided by the base-length $(\alpha - \beta)$, or

$$[(A - B)(A + B)/2 + Aa - Bb]/[\alpha - \beta]$$
$$= ([A^2/2 - B^2/2 + Aa - Bb)/(\alpha - \beta)]$$

The correct value is the mean abscissa

$$X = (\alpha + \beta)/2 = (\alpha^2 - \beta^2)/2(\alpha - \beta)$$

$$= [(A + a)^2 - (B + b)^2]/2[\alpha - \beta]$$

$$= [A^2/2 - B^2/2 + Aa - Bb + a^2/2 - b^2/2]/[\alpha - \beta]$$

Hence the error in the integration is

$$(a^2/2 - b^2/2)/(\alpha - \beta) = (a^2 - b^2)/2(\alpha - \beta)$$

It will be convenient at times to deal with the quantity $(a^2 - b^2) = F$, which will be called the error-function, instead of the error $E = (a^2 - b^2)/2(\alpha - \beta)$.

In the above expressions the error has been expressed in terms of the end-points of the hunt. It is less simple, but more useful, to express it in terms of the integrand ξ and the half-angle of hunt δ.

$$\alpha = A + a = \xi + \delta = (X + D) + (x + d)$$

$$\beta = B + b = \xi - \delta = (X - D) + (x - d)$$

Evidently F is a function of x and d alone, that is, it depends only on the fractional parts of ξ and δ.

Replacement of x by $-x$ replaces a by $-b$ and b by $-a$; replacement of d by $-d$ replaces a by b and b by a. Hence replacement of either x by $-x$ or d by $-d$ interchanges a^2 and b^2, that is, changes the sign of F. Hence F is odd in x and odd in d. It will then suffice to consider the case

$$0 \leq x \leq 1/2 \qquad 0 \leq d \leq 1/2$$

There are two subcases: (I) $x + d \leq 1/2$ and (II) $x + d \geq 1/2$. In Case (I), $x + d \leq 1/2$, $A = X + D$, $B = X - D$, $a = x + d$, $b = x - d$, and

$$F = (x + d)^2 - (x - d)^2 = (x^2 + 2xd + d^2) - (x^2 - 2xd + d^2) = 4xd$$

In Case (II), $x + d \geq 1/2$, $A = X + D + 1$, $B = X - D$, $a = x + d - 1$, $b = x - d$, and

$$F = (x + d - 1)^2 - (x - d)^2$$

$$= (x^2 + d^2 + 1 + 2xd - 2x - 2d) - (x^2 - 2xd + d^2)$$

$$= 4xd - 2x - 2d + 1 = (1 - 2x)(1 - 2d)$$

As x varies from 0 to 1/2, the transition from Case (I) to Case (II) occurs where $x + d = 1/2$, or $x = 1/2 - d$. In each case, F is linear in x. Hence at $x = 0$, $F = 0$; at $x = 1/2 - d$, $F = 2d(1 - 2d)$; at $x = 1/2$, $F = 0$; and between these limits F is linear in x.

For various positive values of d, the values of F are plotted as a function of x, both positive and negative, in Figure 9. The loci of the vertices of the triangles are two sections of parabolas. These parabolas can also be taken as graphs of $d(1 - 2 \mid d \mid) = \pm M(d)$.

Figure 10 shows contours of $\mid F \mid$ as a function of $\mid x \mid$ and $\mid d \mid$. The sign of F is the product of the signs of x and of d.

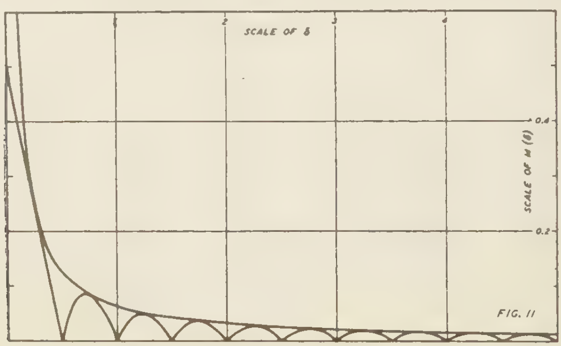
By well-known relations about triangles, as x varies from $-1/2$ to $+1/2$, the maximum absolute value of F is $M(d)$, the mean absolute value of F is $M(d)/2$, the mean value of F is 0, and the root-mean-square value of F is $M(d)/\sqrt{3}$, where $M(d) = 2 \mid d \mid = 2 \mid d \mid \cdot (1 - 2 \mid d \mid)$.

It is evident that $M(d)$ completely characterizes the distribution of F, and hence of the error $E = F/4\delta$, as a function of x, as far as maximum, mean, and expected values are concerned.

It is noted that $0 \leq M(d) \leq 1/4$, $M(0) = M(\pm 1/2) = 0$, and $M(\pm 1/4) = 1/4$.

Hence for given δ, the maximum absolute error is $\leq 1/(16\delta)$, the mean absolute error is $\leq 1/(32\delta)$, the expected error is $\leq 1/(16\sqrt{3}\delta)$. The maximum error vanishes if $d = \pm 1/2$, or if $d = 0$ except in the case $\delta = 0$, when its value is 1/2.

Suppose that $0 \leq \delta \leq 1/2$, hence $D = 0$, $d \geq 0$. Then the error is $F = (2d)(1 - 2d)/4d = 1/2 - d$. Hence as δ varies between 0 and 1/2,



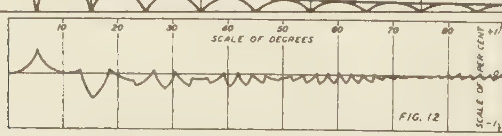


FIG. 11—MAXIMUM ERROR, $M(\delta)$, AS FUNCTION OF HALF-ANGLE OF HUNT, δ

FIG. 12—RELATIVE ERROR OF INTEGRATION AS FUNCTION OF AZIMUTH IN INTEGRATOR WITH 30 TEETH AND HALF-ANGLE OF HUNT $\delta = 5°$

the maximum absolute error varies linearly between 1/2 and 0. The variation of the maximum error $M(\delta)$ with δ is shown in Figure 11.

It is clear that the errors can be made to vanish by making 2δ any positive integer, but if δ is not controlled so accurately, the errors can be kept arbitrarily small by making δ sufficiently large.

In the odograph δ cannot be exactly controlled since when integrating $\sin x\, ds$, the value of δ is proportional to $\cos x$. The half-angle of hunt is about 5°. Near sin 0°, δ amounts to $30 \sin 5° = 30(0.087) = 2.61$, and $2\delta = 5.22$. For $\delta = 2.50$ teeth, the error is 0 tooth = 0 per cent; for 2.61 teeth, the error is 0.0164 tooth = 0.055 per cent, and for 2.75 teeth, the error is 0.0227 tooth = 0.076 per cent.

Hunting in the odograph is non-linear since the time spent on an element dy is proportional not to dy but to $(d \sin y)$ or $(d \cos y)$. The general theory has not been completely worked out, but certain details will be pointed out here.

First suppose that the odograph hunts through an angle $\pm h$, but the integration is continuous, not discrete. Then the integrated values for $\sin y$ and $\cos y$ will be

$$\left[\int_{(y-h)}^{(y+h)} \sin z\, dz\right]/2h = (\sin y \sin h)/h$$

$$\left[\int_{(y-h)}^{(y+h)} \cos z\, dz\right]/2h = (\cos y \sin h)/h$$

Hence the hunting reduces the size of the map in the ratio $1:(\sin h)/h$. If desired, this scale-error can be taken out by suitable gearing, provided h is kept reasonably constant. The relative error in arc-length is $[1 - (\sin h)/h] \approx h^2/6$.

Roughly speaking, this scale-reduction appears as a trend in the error observed with discrete integrations, although the actual errors are generally larger than the scale-error.

For the case of an odograph with 30 teeth on the integrating drums and an angle of hunt of $2h = 2(5°) = 10°$, the errors of integration have been computed and are graphed in Figure 12. It will be noticed that most of the extremes of the errors occur at vertices, that is, at points where one or the other end of the range of hunt is passing from one tooth to another; but in five cases there are proper absolute maxima between transition-points (at 11°.01, 22°.46, 34°.96, 49°.81, 72°.73).

The largest errors occur at points near cos 0° and cos 180°, when the errors may amount to nearly 0.5 per cent. Over most of the range, and especially near cos 90° and cos 270°, the errors are much smaller.

A natural question arises whether the errors can be reduced by properly choosing h and N. It is easily shown that for any smaller value of h the

maximum error nearest cos 0° is larger, amounting to $[1 - \cos (10°.47 - h)]$ if $0 \leq h \leq 10°.47$. How much the error can be reduced by increasing h has not been completely worked out, but the error is not likely to be greatly reduced in this fashion.

The general problem of N teeth and angle of hunt h is complicated and has not been entirely solved. In the vicinity of cos 0°, where the largest errors occur, a simplification can be made by making the approximation $\cos Y = 1 - Y^2/2$.

Let z be the azimuth and h the angle of hunt, y be any such small angle, and let $Y = y\sqrt{N}$. Then $\cos y = \cos (Y/\sqrt{N}) = 1 - Y^2/2N$. Measured in teeth this becomes $N \cos y = N - Y^2/2$. Now during variation of Y due to either the angle of hunt or the azimuth, the transitions from one tooth to the next, measured from the maximum number N, take place at the odd-integer values of Y^2, and the instantaneously integrated values are integral values of $Y^2/2$. Hence the correct values and integrated values, and therefore the errors, all measured in teeth counted from the maximum number N, depend only on the values of Y, that is, on $z\sqrt{N}$ and $h\sqrt{N}$, or otherwise expressed, on $z\sqrt{N}$ and z/h. Hence the actual errors can be expressed by $E = f(z)\sqrt{N}, z/h)/N$.

From this it is concluded that under similar conditions of operation (as defined by $Y = y\sqrt{N}$) of odographs with different numbers of teeth N, the errors near cos 0 are proportional to $1/N$, just as they are near sin 0. Roughly, the errors of the odograph are inversely proportional to the

numbers N of teeth, and depend upon the choice of $\sqrt{N}$ times the angle of hunt, in a fashion not completely determined.

Operation and tests—The effectiveness with which these systems operated in the odograph is demonstrated by various tests which were conducted. Although the standard installation employed by the Army was that in the ¼-ton 4x4 Jeep (see Fig. 13), experimental installations were made in many types of vehicles. In all cases the compass was mounted inside of the vehicle, in spite of the fact that in certain types of vehicles this presented severe problems of compass-compensation. Even for installation in the standard Jeep it was not found possible, for several reasons, to mount the compass in the most favorable position, but the position in which it was mounted was close to the most favorable position.

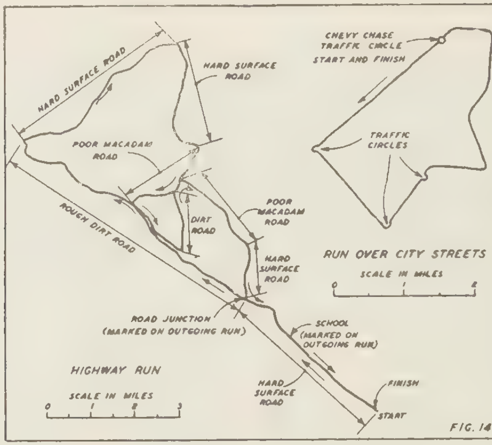
In all cases satisfactory performance of the odograph was obtained, although with the more difficult types of installations considerable skill was required by the operator. Errors in these cases amounted to about four per cent of the total distance traveled. For installation in the standard Jeep and with less-skilled operators errors could be kept smaller than this.

Typical maps obtained with the odograph are shown in Figures 14 and 15. All of these maps, except the first in Figure 15, were obtained with the odograph installed in a Jeep. Each presents a round-trip in which the starting and finishing points were identical for each map. The extent to which the starting and finishing points coincide on the maps is a measure of the accuracy of performance of the odograph. The first map in Figure 14 was obtained in running over various types of roads, as indicated. Several parts of the map are re-traces of the same road which coincide or nearly coincide on the odograph presentation. One notable lack of coincidence is evident; this is due, presumably, to changes in the sub-permanent magnetism of the vehicle during the run. Peculiarly enough, the error at the finish was less than the maximum error obtained during the run—an occurrence which the odograph sometimes haply exhibits. The second map in Figure 14—one of the most perfect ever obtained—shows a run over city streets in which details such as the traffic circles are clearly portrayed. Coincidence of the start and finish "points" which were Chevy Chase Circle coincided better than the width of the mark made by the stylus.

The larger errors which develop in cross-country operation are illustrated in Figure 15 by two runs made over practically identical courses by two different installations. Approximately half of the distance lay over open desert. The going was so difficult that the first vehicle to make the run became stuck in the sand, requiring the use of shovels to dig it out. The second vehicle followed approximately the same course with minor variations in order to avoid the more severe hazards encountered by the first vehicle.

Non-military applications—Numerous non-military applications of the odograph immediately suggest themselves. One of the most interesting of

these from the scientific viewpoint is its use in connection with geophysical and geological surveys where precise mapping is unnecessary but where plane-table work is impractical.



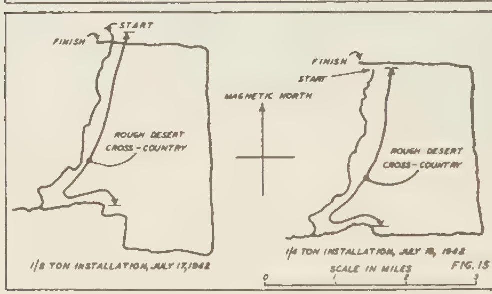


FIG. 14—ODOGRAPH-RECORD OF HIGHWAYS AND CITY STREETS, INSTALLATION IN 1/4-TON JEEP

FIG. 15—COMPARATIVE ODOGRAPH-RECORDS OF ROUGH CROSS-COUNTRY RUNS ON DESERT, INSTALLATIONS IN 1/2-TON JEEP AND 1/4-TON JEEP (ROUTES DIFFERED SOMEWHAT ON SOUTHERN PART)

For scientific work the odograph may be expected to give much more accurate results than were expected or were achieved in military use. It has been shown that, by observing certain precautions in locating the compass, considerable improvement could be obtained even in a military vehicle constructed entirely of iron. The most serious effects were due to the body of the vehicle which was constructed of extremely malleable soft iron—a triumph for the metallurgist but an anathema for the compass-adjuster. The chassis and running gear of the vehicle, constructed of harder steels, presented little difficulty. The advantages which would result from replacing a metal body by one of wood are obvious. In scientific

use it might be expected that the odograph might receive more sympathetic treatment than it would encounter under the strain of military operations.

While it is extremely optimistic regarding the possibilities of the device to suppose that a simplified form of the odograph will ever find such general use as the conventional speedometer-odometer with which every modern car is equipped, the usefulness of such a device to every automobile tourist is evident. One is inclined to wonder if cost would prove an important limitation if a cheaper model of the odograph were manufactured by the millions, and maps of cities and of tourist routes, drawn to the proper scale for use with the odograph, were available at every filling station. Certainly for the special use of those whose business requires them to know exactly where they are at all times the odograph serves as a remarkably reliable navigator.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., September 30, 1945

LETTERS TO EDITOR

(See also pages 14, 76, and 80)

SOLAR AND MAGNETIC DATA, OCTOBER TO DECEMBER, 1946, MOUNT WILSON OBSERVATORY

When the magnetic storm of October 26-27 began, thirteen sunspot-groups were on the visible hemisphere; all were inactive. The largest was an exceptionally long bipolar group, Mount Wilson No. 8251, 18° east, 8° south. The group nearest the center of the disk, No. 8249, was bipolar, 6° west, 9° north.

Table 1—*Magnetic storms*

Greenwich civil time						Range in *H*
Beginning			Ending			
1946	*h*	*m*	*d*	*h*	*m*	γ
Oct. 26	21	..	27	17	..	120
Nov. 24	03	47*	26	04	..	91

*Sudden commencement.

When the storm of November 24-26 began, the large complex bipolar group, No. 8288, was on the central meridian 12° north of the center of the disk.

TABLE 2—*Solar and magnetic data*

Day	October 1946						November 1946						December 1946					
	K_2		H_α bright	H_α dark	No. groups	Mag'c char.	K_2		H_α bright	H_α dark	No. groups	Mag'c char.	K_2		H_α bright	H_α dark	No. groups	Mag'c char.
	Whole disk	Central zone					Whole disk	Central zone					Whole disk	Central zone				
1	..	..	..	..	11[b]	0.5	3	2	3[d]	3	8	0.5	3	2	3	3	9	0
2	3	1	2	1	10	0	3	2	3	3	6	0	3	3	3	2	10	0
3	3	2	2	2	6	0	3	2	3	3	4	0	..	..	..	..	6	0
4	3	3	2	2	5	0	2	2	3	3	6	0	..	..	..	..	..	0
5	2	2	2	2	5[b]	0	3	2	2	3	8	0.5	..	..	..	..	11	0
6	2	2	2	2	5	0.5	3	2	3	4	11	0.5	..	..	..	..	..	0
7	2	1	2	3	5	0	2	2	3	4	11	0	4	3	4	3	9	0
8	3	1	2	2	6	0	3	2	..	..	10	0	3	3	3	3	9[a]	0
9	2	2	2	3	7[b,h]	0.5	3	3	3	3	12	0	3	3	3	4	8	0
10	3	2	2	3	5	0	3	3	3	3	14[b]	0	4	4	4	3	9	0.5
11	3	2	3	4	5[b]	0	..	..	..	..	..	0.5	4	4	4	3	8	0
12	3	2	2	4	8	0	..	..	..	..	..	..	5	4	4	3	9	0
13	3	3	3	4	9	0	..	..	..	..	..	..	4	3	4	3	6	0
14	3	3	3	4	11	0	..	..	..	..	..	..	5	2	4[c]	3	7	0
15	3	3	3	4	14	0	..	..	..	..	12	..	4	3	3	2	9	0
16	3	3	..	..	13	0	..	..	..	..	13	..	4	4	4[c]	2	8	0
17	3	4	4[c]	3	14	0	..	..	..	..	13	..	4	4	4	2	10[a]	0
18	4	4	4[c]	3	15	0	..	..	..	..	14	..	4	4	4	2	8	0
19	4	4	4	3	15[h]	0.5	..	..	..	..	13	..	4	3	4	2	8	0.5
20	4	3	4	3	13[h,i]	0.5	..	..	..	..	..[g]	..	4	3	.	.	8[g]	0
21	3	3	3	3	12	..	..	..	..	..	11	..	..	..	..	..	..[g]	0.5
22	3	3	3	3	11	0	..	..	..	..	10	..	..	..	..	..	..	0
23	3	3	3	3	12	0	..	..	..	..	..	0	..	..	..	..	..	0
24	3	3	3	3	12	0	..	..	4	4	8[g]	1	..	..	..	..	..	0
25	3	2	3	3	15	0	4	4	4	3	8	0.5	..	..	..	..	..	0
26	3	3	3	3	13	0.5	3	3	3	3	8	0	..	..	..	..	..	0.5
27	..	..	..	..	..	1	3	3	3	3	9	0	..	..	..	..	..	0.5
28	..	..	..	..	..	0	3	2	3	3	8	0	3	4	3[d]	2	10	0
29	3	3	3	3	10	0	3	2	3	3	9	0	3	3	3	3	10	0
30	3	3	3	3	9	0	3	2	3	2	10	0	3	2	3	2	9	0
31	3	3	3	2	8	0.5							3	2	3	2	7	0
Mean	3.0	2.6	2.8	2.9	9.8	0.2	2.9	2.4	3.1	3.1	9.8	0.2	3.7	3.1	3.5	2.6	8.5	0.1

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47–49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

a, b Formation of a new group which later developed to average size or larger; (*a*) less than 30° from the center of the disk, (*b*) more than 30° from the center of the disk.

IONOSPHERIC STUDIES IN SOUTH AFRICA TELECOMMUNICATIONS RESEARCH LABORATORY IONOSPHERIC SOUNDER

By T. L. Wadley

The South African Council for Scientific and Industrial Research (CSIR) has recently embarked on a program for recording ionospheric heights and critical frequencies in South Africa, and, in collaboration with other ionospheric bureaus, provides a forecasting service for local users.

Two recording stations have been installed—one in Johannesburg and the other near Cape Town. Data from these two stations are analysed by the staff of the Telecommunications Research Laboratory (TRL) of the CSIR, and, in addition to being used as a basis for local forecasting, are circulated to the United Kingdom, Canada, United States of America, Australia, New Zealand, and India. Reciprocal information from these centres is also received.

The Cape Town equipment had been operated by the Royal Navy at Durbanville, near Simonstown, during the war, and was donated to the CSIR by the Admiralty. The Johannesburg set was developed and constructed in the Telecommunications Research Laboratory and presents some interesting features. A brief description of this equipment follows. Full technical details are contained in TRL Report No. 2 of July, 1946, and copies of this report may be obtained on request from the South African Council for Scientific and Industrial Research, Private Bag 189 Pretoria, South Africa.

The ionospheric sounder of TRL consists of an automatically operated radio-pulse transmitter and receiver covering the frequency-range 2 to 15 Mc/s. It operates every 20 minutes and records a graph of height of reflecting layer against frequency on a single frame of 16-mm film. A record of the time and date is simultaneously photographed.

There are three radio-frequency bands—from 2 to 4 Mc/s, 4 to 8 Mc/s, and 8 to 15 Mc/s. The aerial system consists of three concentrically arranged vertical rhombics, one for each frequency-band. They are terminated by 1000-ohm resistors at the top of the central mast which is 80 feet above ground-level. The same aerial is used to both transmit and receive.

The display tube is a 12-inch long afterglow C.R.O., on which a height-versus-frequency graph is built up by deflecting the spot vertically with the height-time base, and horizontally in synchronism with the frequency-change. The height-time base is triggered in synchronism with the transmitter pulse. The received signals are caused to intensity modulate the C.R.O. beam so as to produce blacked out signals on a light background. The screen is calibrated in height and frequency by modulating the beam with rows of height-markers every ½-Mc/s/km interval of transmission-frequency. The height-marks are spaced every 50 km. The complete

frequency-sweep occupies about eight seconds and a persistent picture is maintained by the afterglow when the equipment is switched to run continuously. When photographing at 20-minute intervals, a single frame is exposed for one complete sweep, that is, eight seconds.

The transmitter and receiver are kept tuned to the same frequency by means of a common oscillator. This oscillator performs the function of the local oscillator in the receiver. In the transmitter it is mixed with a squegging oscillator operating at the intermediate frequency of 1500 kilocycles, so as to produce a radiation-frequency which always differs from the local oscillator by the intermediate frequency.

The radio-frequency tracking in receiver and transmitter is obtained from suitably cut cams which operate the tuning condensers. The same cam-shaft operates the band-switch which switches the coils in all stages simultaneously. The frequency-sweep is in the sequence 4 to 8, 4 to 2, and 8 to 15 Mc/s. This simplifies the operation of the condensers. The necessary arrangements to assemble the picture on the display-tube in the correct sequence are made in the frequency scan generator. The latter consists of slowly charging condenser-circuits which are switched by the cam-shaft.

Common aerial operation is obtained by arranging the aerial tuning circuits to serve both as transmitter output and receiver input. The receiver radio-frequency stage is caused to block during transmit and recover rapidly in time to receive echoes. A suitable large tube is used as a radio-frequency amplifier to enable the grid circuit to handle the peak inverse voltage of about 3000 volts which is developed.

The height-calibration is generated from a 3000-cycle-per-second shock-excited tuned circuit. This is shocked into oscillation in synchronism with the transmitted pulse; after suitable shaping, this wave is applied to the video circuits.

The frequency-calibration is provided from the harmonics of a 0.5-Mc/s oscillator. These harmonics are mixed with the local oscillator of the receiver so as to produce an audio beat as the radiation-frequency passes through a multiple of ½ Mc/s. The intermediate frequency is 1½ Mc/s, which is also a multiple of ½ Mc/s. This audio beat is suitably amplified and rectified. The pulse so formed is caused to gate the height calibration through to the display tube at these ½-Mc/s intervals.

An auxiliary A-Scan C.R.O. is provided for monitoring and tuning purposes, and a small monitoring loudspeaker is included.

The equipment is all mounted in a single rack with the necessary power supplies and time-switching mechanism. The main display tube is mounted separately in a special photographic box. A 16-mm. cine camera with single framing facilities is mounted on the front of the box, on a hinged door. This may be swung aside to allow the tube to be viewed directly.

A specially designed projector with a ground-glass screen is used for

reading the 16-mm film record. This gives an image the same size as the original, and can be conveniently used on a desk top, the dimensions being about 7 by 9 by 20 inches long. The film is developed once a week and the consumption is about 12 feet per week.

Provision has been made on the timing cams to allow the equipment to operate once per minute. The resulting record can be projected by a 16-mm cine projector and a 24- or 48-hour record of variations can be viewed as a motion picture. This technique was used during the recent appearance of the Giacobini-Zinner Comet.

South African Council for Scientific and Industrial Research,
Pretoria, Union of South Africa, January 14, 1947

NOTES

(See also pages 32 and 96)

8. *Air-borne magnetometer*—The meeting of February 1, 1947, of the Philosophical Society of Washington was devoted to a discussion on "Air-borne magnetometer in geophysical exploration" by J. M. Klaasse of the Naval Ordnance Laboratory and F. Keller of the United States Geological Survey. The ingenious features of the design of the air-borne magnetometer, used for the detection of submarines during the war, and its application to geophysical, peace-time surveys, which may be conducted with remarkable speed and accuracy, were discussed.

9. *Finn Ronne Antarctic Expedition*—Instruments and equipment have been loaned by the United States Coast and Geodetic Survey to the Finn Ronne Antarctic Expedition, and Andrew A. Thompson was given training in the use of a dip-circle and theodolite at the Cheltenham Observatory.

10. *Report of geomagnetic activity*—The "Weekly report of geomagnetic activity," discontinued at the beginning of 1947 by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, has been superseded by a weekly report of Cheltenham K-indices, issued by the United States Coast and Geodetic Survey. It has been noted that the Cheltenham K-indices closely approximate the K_A.

11. *Change in scaling of magnetic records by United States Coast and Geodetic Survey*—The United States Coast and Geodetic Survey is suspending the scaling of the mean values for each hour from the magnetic records obtained at its observatories. Beginning in 1946, only the values for the 24th hour of each day will be regularly scaled. Approximate monthly and annual mean values will be derived from the abridged scalings. The new procedure will be important in affording more nearly up-to-date information at all times.

12. *New trial form of report for Cheltenham Magnetic Observatory*—The United States Coast and Geodetic Survey is preparing on a trial basis a new form of report for its Cheltenham Magnetic Observatory. The first number, which is ready for the press, will contain quarter-size reproductions of the magnetograms for the first six months of 1946, together with approximate monthly and annual mean values derived from the abridged scalings discussed above. If adopted finally, the new form of report will supersede for all Coast and Geodetic Survey observatories the series of biennial volumes heretofore issued containing numerical results.

13. *Corrigenda*—The following corrections are necessary in the article by V. C. A. Ferraro on pages 547 to 555 of the December, 1946, issue of the JOURNAL: The second term of the last equation on page 551 should read $\xi_1^2\left(1 - \frac{\lambda\gamma\sigma}{\xi_1^2 + \eta^2}\right)^2$; in the fifth line of the first paragraph on page 553, $H_1^{(1)}$ should read $H_0^{(1)}$.

THE EQUILIBRIUM OF ATMOSPHERIC SODIUM

By David R. Bates

Abstract—Consideration is given to the *Na–Na*$^+$ and *Na–NaO* equilibrium in the Earth's atmosphere. It is probable that in the region of 100 km the free sodium is almost completely ionized and that the concentration of the ions relative to the main atmospheric constituents increases upwards. A possible interpretation to be attached to this is mentioned. It is pointed out that the current theory of the nocturnal emission of the *D*-lines is not reconcilable with the measured altitude of the emitting layer.

1. *Introduction*

The presence of sodium in the upper atmosphere of the Earth has been established by the identification of the *D*-lines in the twilight and nocturnal sky spectrum [see 1, 2 of "References" at end of paper] and various plausible hypotheses as to its origin (for example, from salt particles from the oceans, or from volcanic or meteoric dust), have been made [3]. The actual processes involved in the emission are of considerable interest. It seems highly probable that the twilight effect arises simply from the direct action of sunlight on free sodium atoms. There is some doubt as to the explanation of the nocturnal effect, but Chapman's suggestion [3] that the reaction responsible for providing the necessary excited atoms is

$$NaO + O \rightarrow Na(^2P) + O_2 \qquad (1)$$

has found general provisional acceptance. The object of the present note is to discuss briefly certain aspects of the ionic and chemical equilibrium. Lack of basic data prevents a comprehensive study.

2. *The Na-Na*$^+$ *equilibrium*

From the observed intensity of the twilight emission, the flux of solar quanta, and the known probability of the transitions yielding the *D*-lines, Bates and Massey [4] have estimated that the number of sodium atoms above 70 km is of order 10^9/cm^2 column. Further, Elvey and Farnsworth [5] by a study of the variation of the intensity with the altitude of the illuminated portion of the atmosphere, have found that the associated scale-height is almost constant and is of magnitude about 9 km. The number of sodium atoms per cc at various altitudes can therefore be calculated at once. Table 1 gives the results obtained. For comparison the number of other atoms and molecules per cc [as quoted by Bates and Massey in 4] is also shown.

The extreme rarity of the sodium atoms is very striking and this together with the low ionization-potential (5.12 electron-volts) suggests that it is worth examining tentatively the equilibrium with Na^+ ions.

Rudkjøbing [6] has investigated photo ionization

$$Na + h\nu \rightarrow Na^+ + e \qquad (2)$$

Table 1—*Number of sodium atoms and of other atoms and molecules per cc at various altitudes*

Altitude	No. of Na atoms per cc	No. of other atoms and molecules per cc
km		
70	1.1×10^3	4.0×10^{15}
90	1.2×10^2	3.8×10^{14}
110	1.3×10	2.5×10^{13}

He found the cross-section at the spectral head to be 1.6×10^{-19} cm^2. This value is rather lower than that obtained earlier by Trumpy [7] but is in excellent agreement with the experimental work of Filippov and Prokofjew [8] and is unlikely to be greatly in error. If it is accepted, and the solar radiation is assumed to be that from a black-body at a temperature of rather over 6000°K diluted by a factor 5.43×10^{-6}, then the rate of formation of Na^- during the day can be shown to be about 2×10^{-4}/Na atom/s.

The determination of the rate of disappearance of Na^- is less easy. For the upper levels the most natural process to consider first is radiative electronic recombination as in (3).

$$Na^+ + e \rightarrow Na + h\nu \qquad (3)$$

The appropriate coefficient associated with transitions to the ground state and lower excited states can be derived from the absorption cross-sections given by Rudkjobing [6] by using Milne's well-known relation [9] and that associated with transitions to the higher excited states (regarded as hydrogen-like) from the calculations of Bates, Buckingham, Massey, and Unwin [10]. Combining these a total recombination-coefficient of approximately 2×10^{-12} cc/s is obtained. Consider now the equilibrium between (2) and (3). We have

$$10^8 n(Na) = n^+(Na^+) n_e \qquad (4)$$

where $n(Na)$, $n^+(Na^+)$, and n_e are respectively the numbers of sodium atoms, sodium positive ions, and electrons per cc. From radio measurements n_e is known to be about 10^5/cc at 110 km. It follows at once (using the data in Table 1), that $n^+(Na^+)$ must there be some 1.3×10^4/cc.

Recombination may however also proceed through charge-transfer between positive and negative ions. This type of reaction has been discussed in some detail by Bates and Massey [4, 11]. At one time it was thought that it might explain the large effective recombination-coefficient found in the E-layer by Appleton [12] and others, but the difficulties involved are

very grave and it is felt at present that a more plausible theory can be developed by invoking some other process such as dissociative recombination to molecular ions*. None the less in the problem under consideration the effect of charge-transfer must be examined. Taking the coefficient associated with it to be 10^{-8} cc/s (the maximum probable value) we obtain

$$2 \times 10^4 n(Na) = n^+(Na^+)n^- \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where n^- is the number of negative ions/cc. At 110 km the negative-ion-to-electron ratio is unlikely to much exceed 2×10^{-2} during the day [compare 4] so that, as can readily be seen $n^+(Na^+)$ is about 1.3×10^2/cc. This value, though less than that found with purely electron-recombination, is still much greater than $n(Na)$.

Owing to the comparatively high pressure at the lower levels attachment occurs very rapidly through the little understood Bloch-Bradbury process [compare 11, 13] and the free electrons are so reduced in concentration that they can be neglected as far as recombination is concerned.

The ordinary three-body ionic recombination-process may be important. At 70 km, where the pressure is about 0.1 mm of mercury, its coefficient is almost 10^{-9} cc/s. Noting that the number of negative ions is approximately equal to the total number of positive ions it is easily verified that $n^+(Na^+)$ cannot be greater than some 1.5×10^4/cc. If charge-transfer is again taken to have a coefficient of 10^{-8} cc/sec, $n^+(Na^+)$ becomes 5×10^3/cc (and is probably actually less).

Comparison of $n(Na)$ and $n^+(Na^+)$ (derived on either basis) is very interesting. Unless the recombination-rate has been underestimated it would appear that at high levels the free sodium exists mainly as ions and not as atoms. Further the distribution of the ions (unlike that of the atoms) does not closely follow that of the main atmospheric constituents. Thus their fractional concentration at 110 km is greater than that at 70 km by a factor of at least about 5 or even (if charge-transfer is less rapid than assumed) about 100. If (as is not improbable) the ions provide the principal sodium content of the atmosphere at the levels concerned, their abnormal altitude distribution is of considerable significance in that it supports the view of Cabannes, Dufay and Gauzit [1] that the origin of the sodium is so extra terrestrial.

It would be expected, if the above account is correct, that the twilight-enhancement phenomena would tend to be more pronounced during sunrise than during sunset due to nighttime recombination increasing the number of sodium neutral atoms. Unfortunately owing to the many uncer-

*It will be noted that dissociative recombination cannot occur with sodium ions (which are of course atomic). Certain unexplained discharge-tube results [4], however, make it possible that there is some recombination-process to atomic ions for which allowance has not been made.

tainties it is difficult to make a quantitative estimation of the effect. Precise observational data (particularly at the higher levels where complications due to chemical actions are negligible) might be helpful in elucidating the whole position regarding recombination.

3. *The Na-NaO equilibrium*

In Chapman's theory [3] of the nocturnal emission sodium atoms are being continually freed by collisions between sodium oxide molecules and oxygen atoms per reaction (1). These sodium atoms are assumed to reassociate either through

$$Na + O + X \rightarrow NaO + X \qquad (6)$$

or through

$$Na + O_3 \rightarrow NaO + O_2 \qquad (7)$$

We have, therefore, that in equilibrium

either $$[NaO] \propto [Na]\,[X] \qquad (8)$$

or $$[NaO] \propto [Na]\,[O_3]/[O] \qquad (9)$$

In both cases the concentration of sodium oxide must fall off extremely quickly with increasing altitude and the level of the main emission of the *D*-lines, which occurs where $[NaO]\,[O]$, (that is $[Na]\,[X]\,[O]$ or $[Na]\,[O_3]$) is a maximum, must be very low. Cabannes, Dufay, and Gauzit however found that the emitting layer is located as high as at 130 km. This is in serious conflict with the theory. As in addition Bernard and Dejardin [14] have criticised the accuracy of the estimate further, experimental work is desirable.

Little can be said about reaction (1) except that if endothermic it may well be satisfactory. Though rigorous quantitative discussion of reactions (6) and (7) is not as yet feasible at least the orders of magnitude of the reaction-rates can be examined. It is known from the measurements of Cabannes, Dufay, and Gauzit [1] that apart from fluctuations the nocturnal radiation is maintained constant throughout the night and that the number of quanta emitted is some $2 \times 10^7/\text{cm}^2$ column/s or (assuming a 10-km layer) 20/cc/s. Now each quantum emitted denotes that a sodium atom has been freed. To prevent a high concentration of these developing a rate of oxidation of 20/cc/s must occur.* It is necessary to consider whether either of the reactions proposed can provide this. At an altitude of 70 km we have (using the data given in Table 1 and taking as a crude approximation that the numbers of oxygen atoms and ozone molecules are 5×10^{12}/cc and

*An even faster rate is obviously required if all the sodium atoms freed are not in the ^2P-state.

10^9/cc, respectively) that the coefficient necessary for the three-body process (6) is 1×10^{-30} cm^6/s and that necessary for the two body process (7) is 2×10^{-11} cc/s. Both values are high but if the emission is from below 70 km, smaller coefficients are clearly sufficient and it cannot be said that either process must be dismissed as being too slow.** It is not certain, however, if the variation of $[O]$ and $[O_3]$ at the levels concerned is consistent with the approximate equality of the sunrise and sunset enhancement (at least near its maximum) and the constancy of the nocturnal emission. The photo chemistry of the main atmosphere is of course still largely qualitative.

In spite of their rudimentary nature the figures given above are of value in that they serve to emphasize that it is essential on Chapman's theory for the layer responsible for the emission of the D-lines to be very low as otherwise—quite apart from the conflict with (8) and (9)—impossibly large coefficients are needed. Should the measurement giving the altitude as 130 km be confirmed some new theory must be sought.

Thanks are due to Professor H. S. W. Massey, F.R.S., for his continued interest.

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UNIVERSITY COLLEGE,
London, England, December, 1945

**Doubts earlier cast by Bates and Massey [4] on the adequacy of the oxidation processes did not take into account the possibility that the emission might be from 70 km or lower.

LETTERS TO EDITOR

(See also pages 14, 65, and 80)

REMINISCENCES OF SIR CARRUTHERS BEATTIE AND PROFESSOR J. T. MORRISON

It is with regret that I have to report the deaths of Sir Carruthers Beattie and Professor J. T. Morrison—pioneers in geomagnetic surveys[1] and investigations in Africa. The former died in September, 1946, and the latter in October, 1944, aged 82. We in Africa are indebted to these two men, not only for magnetic observations throughout Africa so generally known from the Royal Society publications, but also for the stimulus given by them in forwarding educational and scientific progress.

I was very fortunate in knowing both Beattie and Morrison intimately from the time I came to South Africa in 1905 until they died. There was no scientist for whom I had more respect than for Morrison. He did not appear in the public eye so much as Beattie did. For many years Beattie was chiefly interested in university development in South Africa. Such work appealed more to the general public than pure scientific research.

Although Morrison did valuable work towards the development of university education, he never let his interest in the modern development of physics lag. I often wondered how in the midst of university administration and teaching he was able to keep himself abreast of modern progress. Morrison was a first-class teacher and much loved by his students. He was a graduate of Edinburgh University and before coming to South Africa had the advantage of doing research work under Professor Tait on thermoelectricity. He was appointed Professor of Natural Philosophy and Chemistry at the Victoria College, Stellenbosch, South Africa, in 1892. As the College developed he was appointed to the Chair of Physics in 1896, and in 1905 to the Chair of Applied Mathematics, which he retained until he retired in 1934.

Beattie and Morrison spent most of 1909 in making a magnetic survey from Cape Town to Cairo. They travelled by different routes to meet again in Cairo after completing their surveys. To carry out a magnetic survey 40 years ago throughout the Continent of Africa was a great undertaking. Transport alone in those days, without the difficult problem of taking accurate scientific observations, was an undertaking in itself.

Morrison was busy with his researches on the circulation of the atmosphere almost to the end of his life. He was a man of great intellect and of singularly endearing and gentle personality.

Hermanus, Cape Province, South Africa, A. Ogg
December 4, 1946

[1]See L. A. Bauer, Researches of the Department of Terrestrial Magnetism, Land magnetic observations, 1905-1910, Carnegie Inst. Washington, Pub. No. 175, **1**, 101-104 (1912); also J. C. Beattie, Report of the magnetic survey of South Africa, Royal Society, London (1909).

GEOPHYSICAL WORK OF THE NATIONAL GEOLOGICAL SURVEY OF CHINA AND OF THE INSTITUTE OF PHYSICS OF THE NATIONAL ACADEMY OF PEIPING OF CHINA

By Wen-Hao Wong

(I) *Academic research*

(*A*) *Seismological observation*—The Chiufeng Seismological Observatory was founded in 1929. It had a complete set of Wiechert seismographs for recording earthquakes of east Asia, and a complete set of the newest type of Galitzin seismographs for recording the remotest quakes. Observation work was headed by Dr. S. P. Lee since the very beginning. A monthly bulletin was published which provided valuable data for many foreign seismological stations. During 1929 to 1937 more than 2300 earthquakes were recorded, 500 of which can be used for the study of subcrustal conditions of the Earth. When Peiping fell to the Japanese in the summer of 1937, the Observatory was lost and observational work suspended.

In 1944 Dr. S. P. Lee built a simple mechanical seismograph, from odds and ends which he could obtain during the blockade, for recording local earthquakes in west China. Many small quakes in Szechuan and Yunnan and a few strong quakes in Japan and Turkey were successfully recorded. Observation was continued till June, 1946, when the instrument was dismantled for transportation to Nanking. The observed data are now being exchanged with many American and European stations. This seismograph has a mass of 100 kg, a natural period of 5 s, and a mechanical magnification of 120. Y. S. Hsieh is now in charge of the work.

(*B*) *Geomagnetic survey*—This work was started in 1939, using a portable magnetic theodolite, under charge of C. L. Liu. Observations of the magnetic declination, inclination, and horizontal intensity had been made at 66 cities of southwestern China by 1944. Such data proved useful for the Air Force during the war.

(II) *Applied geophysics for prospecting by National Geological Survey*

(*C*) *Gravimetric method*—An Askania inclined-beam torsion balance was used by Dr. S. P. Lee and H. L. Chin for investigation of the extension of the lead-zinc deposits of Shuikuoshan, Hunan, in 1937-38. Altogether 610 points were measured and in one locality a lime-stone dome was discovered; in the second locality, a fault was confirmed, and in the third, several gravity highs were located.

The same instrument was used by T. J. Fang for surveying the hematite deposit of Maku, Weining, Kweichow, in 1940. The boundaries of the ore-body, as determined by this survey, agreed with subsequent geologic exploration.

(*D*) *Magnetic method*—Vertical and horizontal magnetic-field balances

were jointly used in surveying the following mineral deposits or geologic problems:

(1) Hematite deposit of Maliutan, near Chinkiang, Szechuan, by Lee and Chin in 1939.
(2) Hematite deposit of Maku, Weining, Kweichow, by Chin in 1940—the ore-boundaries determined checked with torsion-balance data.
(3) Magnetite deposit of Maokupa, Huili, Sikang, by Lee and Chin in 1940.
(4) Magnetite deposit of Mianning, Sikang, by Lee and Chin in 1940.
(5) Magnetite deposit of Panchihhua and Taomakan, Yenpien, Sikang, by Lee and Chin in 1940.
(6) Placer-gold deposit of Kweihuachang, Oopien, Szechuan, by Chin in 1941.
(7) Placer-gold deposit of Taipingssu, Loshan, Szechuan, by Chin in 1941.
(8) The magnetic anomalies of Tsingkangping, Loshan, Szechuan, by Chin in 1942, which were proved to be due to magnetic basalt.

(I) *Gravity measurements by Institute of Physics*

Chang Hung-Chi, in cooperation with P. Lejay, published, in the *Comptes Rendus*, France, 1933-39, results for a total of 256 gravity stations in northeast China, southeast China, south China, north China, and western Yunnan Province.

(II) *Geophysical prospecting by Institute of Physics*

The following reports were prepared:

(1) Ku Kong-Gyiu and Chang Hung-Chi, Resistivity and magnetic survey of the I-Men and An-Ning iron-deposits, Yunnan, China (mimeographed reports in Chinese published in 1939).
(2) Ku Kong-Gyiu, Chang Hung-Chi and Wang Tse-Tchang, Resistivity method applied to the determination of depth of ore-bearing horizon at the Ku-Chiu Tin Mine, Yunnan, China (mimeographed report in Chinese, published in 1940).
(3) Ku Kong-Gyiu, Chang Hung-Chi, and Wang Tse-Tchang, Resistivity survey of the Chao-Tung Lignite Deposit, Yunnan, China, (mimeographed report in Chinese, published in 1941).
(4) Ku Kong-Gyiu, Chang Hung-Chi, and Wang Tse-Tchang, Self-potential surveys at the Lu-Dien Lead-Silver and Pyrite Mines, Yunnan, China (mimeographed reports in Chinese, published in 1941).
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Yunnan, China (mimeographed reports in Chinese, published in 1942).

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(7) Ku Kong-Gyiu, Resistivity and magnetic surveys at the Shueh-Cheng and Hao-Chang Iron Mines, Western Kweichow Province, China (mimeographed reports in Chinese, published in 1944).

(III) *Isostatic work by Institute of Physics*

The following paper is in preparation:

Ku Kong-Gyiu and Chang Chung-Yung, Isostatic reduction of Chinese gravity stations.

THE EXECUTIVE YUAN,
Nanking, China, December, 1946

LETTERS TO EDITOR

(See also pages 14, 65, and 76)

SUMMARY REPORT OF THE SEVENTH GENERAL ASSEMBLY OF THE INTERNATIONAL SCIENTIFIC RADIO UNION (URSI) IN PARIS, SEPTEMBER 27–OCTOBER 25, 1946

Resolutions adopted on proposals of the Executive and Financial Committee

(I) Composition of the Bureau—The first paragraph of Article 6 of the Statutes was modified as follows: "The Bureau of the URSI comprises a President, Vice Presidents, a General Secretary; the Secretary of the URSI also fulfills the functions of the Bureau."

(II) Statutory elections—(*a*) Nomination of Sir Edward V. Appleton as President of the URSI.

(*b*) Nomination of Dr. J. H. Dellinger (United States), Prof. R. Jouaust (France), Dr. H. Sterky (Sweden), and Prof. Dr. van der Pol (Netherlands) as Vice-Presidents.

(*c*) Nomination of Major Prof. A. Dorsimont as General Secretary and of Major Ing. E. Herbays as Secretary.

(*d*) Election of Dr. E. H. Rayner and Prof. R. Mesny as Honorary Presidents of the URSI.

(*e*) Nomination of Presidents of Commissions: Commission I—Dr. J. H. Dellinger (United States); Commission II—Sir Edward V. Appleton (Great Britain); Commission III—Mr. R. Bureau (France); and Commission IV (former Commission V)—Prof. Dr. van der Pol (Netherlands).

(*f*) Designation of the President and General Secretary as delegates of the URSI to the Conseil International des Unions Scientifiques (International Council of Scientific Unions) and UNESCO.

(*g*) Designation of Sir Edward V. Appleton, Dr. J. H. Dellinger, Mr. R. Bureau, and Prof. Dr. D. H. Menzel for the Commission on Relations between Solar and Terrestrial Phenomena, constituted conjointly with the International Unions of Astronomy and of Geodesy and Geophysics.

(*h*) Designation of Sir Edward V. Appleton and Dr. J. H. Dellinger to the Commission on the Ionosphere, constituted conjointly with the International Unions of Astronomy, of Physics, and of Geodesy and Geophysics.

(*i*) Designation of Prof. R. Jouaust as delegate of the URSI to l'Institut International de Coopération Intellectuelle (International Institute of Intellectual Cooperation).

(III) Committee on Auditing of URSI Accounts—This Committee keeps accounts of the General Secretariat and, in order to properly discharge its financial responsibilities, requests that the accounts be examined by a specialized firm.

(IV) Statutory dues—The Executive Committee considers 5000 gold francs as the sum necessary to request annually from UNESCO to carry out the program of the URSI. For this purpose it was decided to modify the sixth paragraph of Article 17 of the Statutes as follows: "The unit annual dues are fixed at 900 gold francs, the gold franc having the value defined by the International Radiotelegraph Conference of Madrid in 1932."

As soon as UNESCO subsidizes the Union, the dues will no longer be collected from countries which are members of UNESCO.

(V) Relation of URSI with UNESCO—The URSI delegates to UNESCO are invited to confer with this international organization (*a*) to obtain an annual appropriation to permit the Union to carry on the program which has been set up and (*b*) to define the position of National Committees whose countries do not belong to the United Nations.

(VI) Publication of the Reports of General Assemblies—It was decided: (*a*) To reduce the size of the reports to make them easier to handle.

(*b*) To publish in full (1) the reports of the inaugural and final sessions, (2) the reports of the National Committees and of the Presidents of the Commissions, (3) the resolutions of the Executive and Financial Committee as well as those of the Commissions, and (4) the list of documents presented at each of the Commissions.

(*c*) To publish in abstract form (1) the minutes of the meetings of the Commissions and (2) the papers presented to the General Assembly; these abstracts, either in French or English, will not exceed 500 words.

(*d*) To distribute these publications to the National Committees free, as soon as the finances of the URSI permit, prorated according to the dues paid.

(*e*) The Executive Committee hopes for the collaboration of the Presidents of the Commissions in the editing of these reports.

(VII) Publications of the URSI—(*a*) *Monthly Bulletin:* It was decided to renew publication of this *Bulletin*, which will contain only (1) communications emanating from the General Secretariat and (2) information relating to Ursigrams not appearing in any other publications.

(*b*) It was also decided to renew the publication of the "Special reports of the URSI", emanating from members of the Union, and presenting an interest of general order.

The selection of these papers shall be made by the Bureau of the Union, in collaboration with the Presidents of Commissions.

(VIII) Mixed Commission on Radio Meteorology—The URSI suggests to the International Council of Scientific Unions the constitution of a Mixed Commission on Radio-Meteorology.

(IX) Activity of National Committees—(*a*) It would be highly desirable for the National Committees, following the example of the National

American Committee, to set up committees and periodically hold national meetings.

(b) The URSI wishes to acknowledge the contribution made to radio scientific research by the amateurs, and recommends to the National Committees that they direct and encourage, in their respective countries, the work of the amateurs. To this end, it is recommended that the National Committees get in touch with the General Secretariat of the Union, which will issue general instructions, after consultation with the Presidents of the Commissions.

(X) Eighth General Assembly—The next General Assembly will take place in 1948: the exact date and place to be fixed later. The Executive Committee expressed the hope that this Assembly be held in Sweden, during the month of August.

Some 90 papers were presented at the General Assembly; these were by representatives in Australia, Belgium, France, Great Britain, Netherlands, Sweden, Switzerland, and United States of America. (A complete list of titles of the papers may be obtained on request to Dr. Newbern Smith, Secretary of the American Section URSI, National Bureau of Standards, Washington 25, D. C.) Among papers, which appear of interest to readers of the JOURNAL, are the following:

A. and E. Vassey, Sur quelques relations entre la lumière du ciel nocturne et les régions ionisées de l'atmosphère.

N. Stoyko, L'influence des perturbations magnétiques sur la vitesse apparente de propagation des ondes courtes.

J. Gauzit, A propos de la physique de l'ionosphère.

O. Rydbeck, Mesures ionosphériques effectuées en Suède au cours de l'éclipse de soleil, en 1945.

R. Naismith, The presentation of ionospheric data.

R. Naismith, Report on ionospheric measurements during a solar eclipse.

D. H. Menzel, Sun and the ionosphere.

H. W. Wells, J. M. Watts, and D. S. George, Detection of rapidly moving ionospheric clouds.

Newbern Smith, The longitude effect in $F2$-layer characteristics.

J. G. Elias and J. van den Wijck, Influence d'un champ magnétique extérieur sur la propagation des ondes électromagnétiques.

R. Rivault, Réflexions multiples des atmosphériques entre le sol et l'ionosphère.

R. Bureau, Eruptions chromosphérique et ionosphère.

L. d'Azambuja, Note relative à la réalisation d'un service d'information rapide de l'apparition, sur le soleil, d'éruptions chromosphériques importantes.

J. Loeb, L'hodoscope (appareil matérialisant la trajectoire d'une particule électrisée dans un champ magnétique).

NATIONAL BUREAU OF STANDARDS,
Washington 25, D. C., January 22, 1947

NEWBERN SMITH, *Secretary*,
American Section, URSI

COMMITTEE ON GEOPHYSICAL SCIENCES OF THE JOINT RESEARCH AND DEVELOPMENT BOARD (U.S.A.)

The first and organizational meeting of the Committee on Geophysical Sciences of the Joint Research and Development Board was recently held in Washington, D. C. This Committee was established by the Joint Research and Development Board to assist the Board in carrying out the provisions of its Charter in those departments of scientific research lying within the geophysical sciences. These include the following:

Physics of the upper atmosphere in the region where cosmic rays and ultra-violet light are of considerable significance and in which long-range rockets and possibly jet-planes will attain great speeds.

Meteorology of the lower atmosphere, where the weather is of more significance and in which all ordinary flying is now done—the area in which thunderstorms and other electrical phenomena create hazards to flight and difficulties in the control of guided missiles.

Geomagnetism, the phenomenon of the Earth as a great magnet which produces the north and south magnetic poles and the variations in both direction and strength of the magnetic lines of force surrounding the Earth.

Geology, the study of the Earth, its structure and its surface phenomena, of mountains and minerals, sediments and fuel resources.

Hydrology, the study of the water content of the Earth both in the atmosphere, on or in the ground, and in the sea; water is the most significant single factor affecting life on this planet.

Oceanography, the study of the great mass of water covering more than 72 per cent of the Earth and within which are both physical and biological phenomena of great significance.

Seismology, the study of earthquakes and the movements of the crust of the Earth which cause or result from them.

Geodesy, the study of the shape of the Earth; the fact that the Earth is not a perfect sphere and is slowly changing its shape is of increasing significance in modern long-range navigation and in long-range missile control. The science of Cartography is concerned with the many different methods and devices for showing the true relation of features of the Earth's surface. The air navigator requires a different map from that used by the sea navigator and both require weather maps. The kinds and special uses of maps are legion.

These are only a few of the specialized fields of science and research which are now not only useful but essential to modern war.

The members of the Committee on Geophysical Sciences of the Joint Research and Development Board are: Dr. Roland Beers, Chairman, formerly of the faculty of Massachusetts Institute of Technology and a field geophysicist of wide experience; Dr. Carl G. Rossby, Head of the Department of Meteorology, University of Chicago; Dr. Chester R. Longwell, Professor of Geology, Yale University; Samuel B. Morris, General Manager and Chief Engineer of the Department of Water and Power, Los Angeles, California, and former Dean of Engineering at Stanford University; Rear Admiral R. O. Glover, Hydrographer of the United States Navy with Dr. R. H. Fleming, Hydrographic Office, Navy Department, as deputy; Captain Howard B. Hutchinson, aerologist with the Office of Naval Research, U. S. Navy with Lt. Comdr. D. F. Rex, Office of Naval Research, as deputy; Colonel B. G. Holzman, a member of the staff of the Deputy Chief of Air Staff for research and development, who conducted weather research in Labrador, Greenland, and England prior to the invasion of Normandy, with Lt. Col. Moss Yater, Research and Engineering Division, Army Air Force, as deputy; Colonel D. N. Yates, Chief Air Weather Service, who served as staff weather officer for General Eisenhower and General Spaatz during the European operations, with Col. W. S. Stone, Chief of Staff, Air Weather Service, as deputy.

The Committee will coordinate the research and development activities of the Army and Navy which require the specialized techniques of the many geophysical sciences. It will be assisted by a number of panels composed of scientists, engineers, and consultants drawn from government, industrial, and academic institutions.

Washington 25, D. C.,
February 14, 1947

C. S. Piggot, *Executive Secretary,*
For the Committee

COSMIC-RAY RESEARCH IN B-29 LABORATORY DETERMINES NATURE OF SECONDARY PARTICLES

Research in a B-29 "flying laboratory" has contributed to knowledge of cosmic radiation by proving that a large proportion of mesotrons—a part of the rays in the Earth's atmosphere—are produced by electrically-charged particles.

The National Geographic Society, the Bartol Research Foundation, and the Army Air Forces joined last summer in an extensive series of B-29 flights to record the number of mesotrons in the air [see Terr. Mag., **51**, 303-304 (1946)]. Tests were made at altitudes ranging from one to more than six miles between southern Canada and the magnetic equator over northern Chile.

The little-known cosmic rays represent a release of atomic energy far greater than the energy unleashed in the atomic bomb, although so far this power cannot be harnessed. The Army Air Forces have been interested in studying the effect of the rays on electrical and radio equipment and on materials used in guided missiles.

Most penetrating particle—In summarizing the results of the experiments, Dr. Swann, Director of the Bartol Research Foundation, observed, "We might say that the father of the mesotron is a proton, and he has ten children." Previously there had been some question as to the nature of the mesotrons' parents.

"The mesotron, discovered comparatively recently, is the most penetrating charged particle in physics. We know of mesotrons which can pass through 75 feet of lead. We know, moreover, that the mesotrons are born in the atmosphere, since most of them live for less than a thousandth of a second, and there is no place outside of our atmosphere from which they could have come. They would have died long before they had reached the Earth.

"Charged particles are bent in their paths by the Earth's magnetic field as they approach the Earth, the bending being, in general, appreciable for several thousand miles outside of the Earth's atmosphere. This bending is of such a nature as to result in more rays entering at high latitudes than at low latitudes.

"If, therefore, the parents of the mesotrons are charged particles, we should expect to find that the number of their offspring observed per second by a vertically directed cosmic-ray telescope would increase with latitude. Our observations were designed to measure only mesotrons in that the apparatus was covered with a sufficient thickness of lead to absorb the electrons, the other main type of cosmic-ray particles in the atmosphere.

"It was found that at 25,000 feet an increase of intensity of about 50 per cent was observed in passage from the magnetic equator to 48° north magnetic latitude. At 33,000 feet the increase was about 33 per cent. These results established the fact that at least a considerable number of the mesotrons are born from parents which are charged particles."

Accounts for decrease—In his report to the National Geographic Society, Dr. Swann said that the decrease in the percentage increase (33 per cent at 33,000 feet and 50 per cent at 25,000 feet) "can be accounted for if we assume that there is a dilution of the radiation arising from the magnetic field sensitive primaries by mesotrons whose parents are not field-sensitive.

"The required kind of dilution of the ratio could occur by the production of mesotrons in the lead over our apparatus, provided that the radiation responsible for this production of mesotrons was rapidly absorbed between 33,000 feet and 25,000 feet, and was not field-sensitive in its journey to our atmosphere from its point of origin.

"Photons (X-ray-like particles) could be representative of such a radiation. However, it is more intriguing to suppose that the radiation in question is a charged-particle radiation of such high energy as to be insensitive to the Earth's magnetic field. Our theories are longing for guidance as to the manner in which the production of mesotrons by charged particles depends upon the energy of these particles.

"Our experiments, interpreted to the foregoing end, would imply a rapid increase of mesotron production, per unit of path traveled, with energy; for, by the very fact of such abnormally high activity of the high-energy particles in producing mesotrons would those particles be rapidly absorbed as they pass through the atmosphere.

"In this way we are able to understand how these high-energy particles, constant in their intensity all over the Earth, would produce considerably more mesotrons in the lead of our apparatus at 33,000 feet than they would produce at 25,000 feet. It may be added that, in spite of the fact that the ratio of intensity at 48° north to that at the magnetic equator diminishes from 25,000 feet to 33,000 feet, the actual difference between the intensities at these latitudes increases with altitude, as our experiments show to be the case."

Could have predicted mesotrons—"Even had we not known of the existence of such a particle as the mesotron, a particle intermediate in mass between the electron and the proton, our experiments could have predicted such a particle. Theory indicates that the steady increase in the primary radiation—intensity with increase of latitude is an increase composed of successive editions of rays of smaller and smaller energy.

"When we reach a latitude such that the rays entering on further increase of latitude are of such small energy that they cannot penetrate down to the point of observation, no further increase of intensity with further increase of latitude is to be expected. If the entering particles split up into lighter particles such as the mesotrons, the energies of these mesotrons will be less than those of the primary particles and they would, therefore, not be expected to penetrate as far as the primaries.

"At 33,000 feet we find the intensity measured increases no further with increase of magnetic latitude beyond 48° north. However, a proton which could enter at as low a latitude as 48°, could travel much further through the atmosphere than the distance down to 33,000 feet plus the thickness of the lead, if it lost energy only by the ordinary processes by which charged particles lose energy—the splitting of atoms into charged ions.

"If, however, the primary particles split into, say, ten lighter particles, these particles will have less energy and so less penetrating power than the primaries would have had if they lost energy only by producing charged ions.

"The experimental fact that the intensity does not increase beyond 48° north practically necessitates the existence of a particle lighter than the proton; and the latitude of 48°, where the increase in question stops, is well in harmony with the assumption that the mesotron has a mass one-tenth of that of the proton and that each proton produces ten mesotrons."

A slight reservation is desirable, Dr. Swann said, to allow for the conclusion that the mesotrons produced at very high altitudes may be in part produced by singly-charged helium atoms. Such mesotrons, together with their parents, would be expected to be confined to such high altitudes.

THE NATIONAL GEOGRAPHIC SOCIETY,
Washington 6, D. C., January 30, 1947

GILBERT GROSVENOR,
President

FIVE INTERNATIONAL QUIET AND DISTURBED DAYS FOR APRIL TO JUNE, 1946

Reports of geomagnetic activity for the second quarter of 1946 have been received from a sufficient number of observatories so that the International quiet and disturbed days can be selected in accordance with the method outlined on pages 219-227 in the December, 1943, issue of this JOURNAL. The selection is based on the reports of magnetic character on a scale of 0, 1, and 2 from 37 observatories and of K-indices from 29 observatories.

Month	Quiet					Disturbed				
April	11	19	20	21	30	9	14	15	23	24
May	14	15	19	27	30	6	9	11	22	23
June	2	3	23	24	30	7	8	12	19	29

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington 15, D. C., February 4, 1947

W. E. SCOTT

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1946

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h $01^m.3$ W. of Gr.)

October 26-27—A moderately disturbed period began rather slowly at about 04^h GMT, October 26, and was characterized by long-period oscillations until about 15^h of the same date when activity nearly ceased. However, at about 23^h there appeared short-period, low-amplitude oscillations which soon became superposed on rather large bays. A maximum of disturbance was reached between 08^h and 15^h GMT, October 27, when K-indices of 9, 8, and 7 were recorded. The traces for several days following this moderately severe storm showed signs of slighter disturbances.

October 31-November 1—The moderate disturbance of this date may be said to be a continuation of stormy period described above. From a slightly disturbed period, activity began rather abruptly at a few minutes before 08^h GMT, October 31. This abrupt activity consisted chiefly of variations of large amplitude and long period, and continued until 19^h on November 1. Three K-indices of 6 were recorded during the most severe portion of the disturbance.

November 24-25—A minor disturbance of rather long duration began abruptly at 03^h 45^m GMT, November 24. A maximum of activity was reached between 12^h and 14^h, November 24, when a K-index of 8 was recorded. Slight to moderate disturbances continued through November 25.

December 19—A brief period of moderate disturbance began gradually at about 07^h GMT, December 16, and continued until about midnight. Greatest activity was recorded during the 12th hour when a K-index of 7 was reached.

JOEL B. CAMPBELL, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

OCTOBER TO DECEMBER, 1946

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or 5^h $07^m.4$ W. of Gr.)

October 26-28—A mild magnetic storm began between 21^h and 22^h GMT, October 26, and continued until about 01^h, October 28. All three elements were disturbed, the greater disturbance occurring within the first twelve hours and consisting of irregular oscillations of moderate amplitude. For the remainder of the storm some short-period motion and minor irregular oscillations appeared. Five K-indices of 5 and four of 4 were recorded.

WILLIAM E. WILES, *Observer-in-Charge*

Tucson Magnetic Observatory

October to December, 1946

(*Latitude 32° 14'.8 N., longitude 110° 50'.1 or 7^h $23^m.3$ W. of Gr.*)

October 26-27—A moderate storm began without sudden commencement during the first half of the Greenwich day, October 26. The greatest activity occurred between 22^h on the 26th and 12^h on the 27th, and the storm continued until the end of October 27, Greenwich time. Ranges: D, 14'.5; H, 155 gammas; Z, 42 gammas.

November 5-6—A sharp increase of 40 gammas in H beginning at 09^h 24^m GMT, November 5, marked the beginning of a moderately stormy period that was peculiar because of its relatively small over-all ranges of the elements. The principal activity was of comparatively short period. The storm ended at the close of the Greenwich day, November 6. Ranges: D, 10'; H, 87 gammas.

November 15-16—A disturbance having principal characteristics similar to the storm of November 5-6 began at 07^h 54^m GMT, November 15, with a sudden increase of 46 gammas in H and continued for about twenty-four hours. Ranges: D, 8'.5; H, 84 gammas.

November 24-25—At 03^h 46^m GMT, November 24, H increased 41 gammas to mark the beginning of a moderate storm. Some long-period oscillations on which were superimposed shorter-period fluctuations characterized the first twelve hours of disturbance. Following a period of relative calm, slight activity began again about the middle of November 25. The storm lasted until the end of the Greenwich day, November 25. Ranges: D, 13'.5; H, 112 gammas.

December—There were no disturbances of storm intensity during the month of December.

C. Edward Westerman, *Observer-in-Charge*

Zô-Sè Observatory

September to December, 1946

(*Latitude 31° 06' N., longitude 121° 11' or 8^h 04^m 45^s E. of Gr.*)

September 16-24—The equinoctial magnetic activity began at 13^h 47^m GMT, September 16, with an abrupt rise of 15 gammas in H which was followed by a moderate disturbance with an amplitude of 120 gammas lasting some eighteen hours. At 23^h 51^m, September 17, sudden commencement of a major storm occurred. H swiftly decreased by 210 gammas in two hours and moderate oscillations followed around that low value during four hours, then was a new decrease of 100 gammas. Disturbed conditions prevailed with irregular oscillations and increasing values in the morning of September 18. At 12^h 10^m there was a new fall of the curve by 135 gammas;

milder conditions continued until 14^h 56^m on the 18th, when a rapid increase of 140 gammas in forty minutes and two large oscillations exceeding 100 gammas brought the curve near normal values. At 10^h 10^m, September 19, an increase in the activity was noted and two large oscillations of 80 gammas in range. Smooth conditions prevailed thereafter. The evening of September 20 and the morning of the 21st were calm. At 17^h 13^m, September 21, a new, very sharp beginning of 49 gammas preceded the major storm of the equinox. Activity at first was reduced till 04^h 23^m September 22, when a new rise of 20 gammas was followed by a drop of 170 gammas and the curve was slowly recovering when a violent sudden start of 45 gammas took place at 10^h 11^m with rapid and spasmodic fluctuations during more then eight hours. The storm was then at its maximum. Disturbance abated in the evening of the 23rd and calm was absolute near 17^h of the 24th.

The range was 300 gammas in *H* for the first storm and 375 gammas for the second beginning at 10^h 11^m.

Wireless communications were disrupted during the second storm.

According to reports, kindly supplied by the Chinese Government Radio Administration, the following sudden interruptions (fade-outs) were noted:

Date	Circuit	Time
Sep. 14	....	No fade-out
15	European	14^h 00^m–15^h 30^m
	South France; U.S.A	13^h 41^m–14^h 45^m
16	....	No fade-out
17	European	14^h 00^m–16^h 36^m
	South France; U.S.A.	No fade-out
18	European	15^h 00^m–17^h 15^m
	South France; U.S.A.	15^h 15^m–15^h 30^m
19	European	04^h 15^m–06^h 25^m and 15^h 00^m–16^h 00^m
	South France; U.S.A.	13^h 00^m–14^h 30^m
20	....	No fade-out
21	European	06^h 00^m–06^h 30^m and 14^h 15^m–14^h 30^m
	South France; U.S.A.	No fade-out
22	European	No fade-out
	South France; U.S.A.	05^h 00^m–06^h 00^m 15^h 30^m–16^h 30^m and 22^h 00^m–23^h 00^m
23-24	European and South France and U.S.A.	Interruptions throughout day; different wave-lengths tried without success.

October 20—Small beginning of 32 gammas at 03^h 10^m GMT, October 20, with a moderate disturbance, not exceeding 68 gammas in range.

November 5—Small activity lasting a few hours, beginning with a sudden start of 30 gammas at 09^h 38^m GMT, November 5.

November 13-15—At 01^h 27^m GMT, November 13, a very fine, clear, and sharp pulse of 2′ 30″ was registered in D; not so well marked on the curves of Z and H. A sudden beginning of 31 gammas followed at 07^h 54^m, November 15, with a very moderate disturbance of a range of 100 gammas.

November 24-25—Abrupt beginning of 45 gammas at 03^h 47^m GMT, November 24, and small perturbation of 150 gammas in amplitude not exceeding twelve hours.

December 4—H increased 10 gammas at 17^h 15^m GMT, December 4, in eight minutes, clearly separating a moderate activity from very quiet conditions prevailing the days before.

December 14—During 07^h 03^m to 07^h 25^m GMT, December 14, there occurred a rather well-marked pulse in D which was clear also in Z. No sudden beginning was noted following the pulse, but magnetic activity was noted on the 17th.

December 19—Small beginning lasting eight minutes took place with a characteristic drop in H of more than 130 gammas.

December 22—Small sudden commencement occurred at 05^h 19^m GMT, December 22, with slight activity.

December 23 and 25—During 15^h 10^m to 15^h 42^m GMT, December 25, there was a well marked pulse in D. A sudden beginning of 21 gammas at 19^h 13^m, December 25, and very small activity followed. Two special marks in H and Z of pulse form were noted on the 23rd, at 05^h 04^m to 05^h 14^m and at 05^h 44^m to 06^h 10^m.

M. Burgaud, *Director*

Alibag Magnetic Observatory

October to December, 1946

(Latitude 18° 38′ N., longitude 72° 52′ E. or 4^h $51^m.5$ E. of Gr.)

November 5-6—A moderate disturbance commenced suddenly at 09^h 22^m, GMT, November 5, and continued till about 17^h 30^m, November 6. All the three elements recorded moderate fluctuations. The highest K-index attained during the period was 5.

November 20-22—A moderate disturbance commenced at about 10^h GMT, November 20, and continued till about 00^h, November 22. The highest K-index recorded was 5 during 9-12 hours GMT on November 21.

November 24—A moderate magnetic disturbance commenced suddenly at 03^h 46^m GMT, and continued till about 16^h 30^m, giving one K-index of 5 and one of 6 for three hourly intervals. Ranges: H, 215 gammas; Z, 24 gammas; D, 3′.4.

M. P. Rao, *Assistant*

Apia Observatory

July to September, 1946

(Latitude 13° 48'.4 S., longitude 171° 46'.5 or 11^h 27^m.1 W. of Gr.)

July 7-9—Minor activity commenced at 03^h 27^m GMT, July 7, and continued until 10^h 07^m, July 9. K-indices of 5 and 4 were recorded.

July 18-19—A sudden commencement at 09^h 05^m GMT, July 18, was followed by a period of mild activity which continued until 14^h 15^m, July 19. K-indices of 4 were recorded during the sixth three-hour period, July 18, and the fourth three-hour period, July 19.

July 22-23—There was minor activity between 22^h 45^m GMT, July 22, and 17^h 18^m, July 23. Maximum K-index of 4 occurred during fourth three-hour period, July 23.

July 25-31—A sudden commencement at 18^h 47^m GMT, July 26, marked the beginning of a stormy period. Rapid, irregular oscillations continued until 09^h 41^m, July 27, when the disturbance became milder in form. Minor activity continued throughout July 26, becoming intensified at 21^h 22^m, July 28. Irregular movements with superposed oscillations were apparent until 18^h 35^m, July 30. There was marked disturbance in Z as well as H. K-indices of 7 occurred during the seventh and eighth three-hour periods on July 26, and K-indices of 8, 6, 6 were recorded during the first, second, and third three-hour periods, July 27.

August 14-15—A period of minor activity commenced at 05^h 21^m GMT, August 14, and continued until 06^h 36^m, August 15. Maximum K-index 5 was recorded during the third three-hour period, August 14.

August 17—There was very minor activity between 06^h and 22^h 21^m GMT, August 17. Maximum K-index 4 occurred during the third three-hour period.

August 30-31—Mild activity began at 18^h 35^m GMT, August 30, and was followed by a sudden commencement to more marked activity at 22^h 39^m, August 30. The movement, irregular in nature, continued until 23^h 14^m, August 31. K-indices 6, 7, 6 occurred during the first, second, and third three-hour periods, August 31.

September 16-17—A period of minor activity began with a sudden commencement at 13^h 48^m GMT, September 16, and continued until 05^h 27^m, September 17. K-indices of 4 were recorded.

September 17-20—A sudden commencement at 23^h 51^m GMT, September 17, marked the beginning of a period of activity of an irregular nature which continued until 09^h 39^m, September 20. There was some movement in D while that in Z was quite marked. K-indices of 5, 6, and 7 occurred on September 18 and K-indices of 5 were recorded during the first and second three-hour periods, September 19.

September 21-24—After a sudden commencement at 17^h 14^m GMT,

September 21, there was a period of minor activity followed, at 04^h 09^m, September 22, by rapid oscillatory movement. This continued until 03^h 46^m, September 23, and then became more bay-like in form. Activity continued until 17^h, September 24. Oscillatory movement was well shown in Z at the height of the storm and appeared to a very much lesser degree in D. K-indices of 6, 7, and 8 occurred on September 22 and 5 and 6 on September 23.

September 27-30—A negative bay at 06^h 03^m GMT, September 27, introduced a period of mild activity which continued until 12^h 25^m, September 30. K-indices of 5 were recorded during the second, third, and fifth three-hour periods, September 28.

J. W. Beagley, *Director*

Watheroo Magnetic Observatory

October to December, 1946

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h 43^m.5 E of Gr.)

October 20—A moderate disturbance began at 03^h 09^m GMT, October 20, with a fairly sudden commencement. The horizontal intensity dropped by 7 gammas, then increased by 23 gammas within two minutes. D increased by 2′, then decreased to normal, while Z rose 10 gammas and then slowly decreased. The disturbance in all elements was not very great and consisted of somewhat rapid fluctuations superimposed upon larger and slower movements. Quiet conditions prevailed again by 23^h. Ranges: D, 14′; H, 69 gammas; Z, 77 gammas.

October 26-27—A moderate storm was recorded on October 27. The disturbance did not have a definite beginning, conditions having been somewhat unsettled from 06^h GMT, October 26. Small, rapid fluctuations commenced around 22^h, October 26, and these continued until 09^h, October 27, with a few slow, large swings of the order of 25 gammas. A very sharp peak occurred in H at 09^h 20^m, H having increased by 57 gammas in the previous fifteen minutes. There was an increase in the other elements also, the peak in D and Z occurring simultaneously at 09^h 10^m. At 16^h 00^m, following a few slow, large swings, H increased by 30 gammas in twelve minutes, D dropping by 8′, and Z decreasing by 41 gammas in the same time. Conditions were quiet again by 17^h 00^m. Ranges: D, 12′; H, 73 gammas; Z, 129 gammas.

November 5—At 09^h 24^m GMT, November 5, H suddenly dropped by 5 gammas, then almost immediately rose again, increasing by 40 gammas in the next three minutes. D and Z showed a series of small, regular oscillations. From 09^h 27^m onward, the movements were on the whole irregular and slow and not of great amplitude. However, conditions remained unsettled until about 24^h, November 6. Ranges: D, 12′; H, 115 gammas; Z, 123 gammas.

November 11—A "sudden commencement" was recorded at 11^h 26^m GMT, November 11, when H increased by 34 gammas in two minutes, with small, sharp variations in D and Z. However, there was no marked departure of the elements from normal following this commencement.

November 15—A "sudden commencement" was recorded at 07^h 54^m GMT, November 15, when H increased by 47 gammas in two minutes, D dropped by $2'$, and Z decreased by 16 gammas. Slightly disturbed conditions prevailed afterward until about 08^h, November 16. Ranges: D, $14'$; H, 79 gammas; Z, 62 gammas.

November 24—A moderate disturbance of short duration commenced suddenly at 03^h 46^m GMT, November 24. H was momentarily depressed by 2 gammas, then increased by 34 gammas in about half a minute, moving too rapidly to leave a record. D dropped and then increased in the same period, the swing being $4'$. Z dropped and then increased over a range of 16 gammas, followed by a decrease of 24 gammas in the next two minutes. Fairly rapid, small-amplitude oscillations, superimposed upon slow swings of moderate amplitude, were recorded in all elements during the following nine hours. H showed a sharp peak at 13^h 14^m, increasing by 42 gammas in five minutes, then dropping through 96 gammas by 13^h 43^m. This effect was not quite so marked in D and Z. H rose fairly markedly during the following two hours and, except for a few slight fluctuations which continued for the next two days, conditions were normal by 17^h, November 24. Ranges: D, $14'$; H, 145 gammas; Z, 150 gammas.

December 25—There was a fairly sudden commencement at 19^h 14^m GMT, December 25, H increasing by 25 gammas in one minute. West declination increased by $1'$, then decreased by $3'$, while Z increased by 4 gammas, then decreased by 21 gammas, the whole movement occupying six minutes. There was no great departure of the elements from normal, but irregular movements were recorded for five hours after the commencement, by which time conditions were comparatively quiet once more. Ranges: D, $13'$; H, 25 gammas; Z, 62 gammas.

F. W. Wood, *Observer-in-Charge*

Hermanus Magnetic Observatory

October to December, 1946

(*Latitude 34° 25'.2 S., longitude 19° 13'.5 or* 1^h $16^m.9$ *E. of Gr.*)

October 8-9—A disturbance of very moderate intensity began gradually at 22^h GMT, October 8, and continued until about 24^h, October 9. Small, sharp oscillations during the first five three-hour periods of October 9 were followed by large, shallow bays between 22^h and 24^h.

October 20-22—Small, abrupt changes in all three elements at 03^h 09^m GMT, October 20, were followed by two days of mild activity.

October 26-27—A storm of moderate intensity commenced gradually about 00^h GMT, October 26, the most disturbed period being that between 21^h, October 26, and 18^h, October 27. A K-index of 6, the highest in October, was recorded during the last three-hour period of October 26.

November 5-6—A period of moderate activity began with a sudden commencement at $09^h\ 22^m$, November 5, and continued until about 18^h, November 6. The highest K-index was 5 for the period 12^h to 15^h, November 6.

November 11-12—Following a two-day period of mild activity, abrupt changes occurred in all three elements at $11^h\ 25^m$ GMT, November 11. The disturbance subsided at 06^h, November 12.

November 15-16—A very mild disturbance began with a sudden commencement at $07^h\ 54^m$ GMT, November 15 (H increased by 33 gammas in seven minutes), and continued until about 17^h, November 16.

November 19—A large, complete oscillation of period 1.5 hours and K-index 5 appeared on all three traces between $21^h\ 45^m$ and $23^h\ 15^m$ GMT, November 19.

November 20-22—Small, abrupt changes in all three elements at $10^h\ 05^m$ GMT, November 20, were followed by sporadic movements until 18^h, November 22. At $00^h\ 45^m$, November 21, H decreased by 41 gammas in ten minutes. Three K-indices of 5 were recorded between 00^h and 12^h, November 21.

November 24-26—A sudden commencement occurred at $03^h\ 45^m$ GMT, November 24, but the disturbances which persisted until 06^h, November 26, were of weak intensity, except during the period between $13^h\ 09^m$ and $14^h\ 15^m$ when violent movements were recorded. K for the period 12^h to 15^h, November 24, was 6, while the ranges for this day were as follows: D, 38′; H, 170 gammas; Z, 142 gammas.

November 30—Crochet-type deflections appeared on all three traces at $12^h\ 30^m$ GMT, November 30.

December 4-8—A period of minor activity began with small, abrupt changes in all three elements at $17^h\ 13^m$ GMT, December 4, and continued until about 06^h, December 8. Sudden movements were recorded at $11^h\ 10^m$, December 5.

December 14—A sharp increase of 25 gammas in H was recorded on an otherwise quiet trace between $07^h\ 00^m$ and $07^h\ 09^m$ GMT, December 14, with accompanying very slight disturbances in D and Z.

December 19-26—The following periods were moderately disturbed: At 06^h to 20^h GMT, December 19; 08^h to 15^h, December 21; $05^h\ 03^m$ to 11^h, December 23; $19^h\ 12^m.5$ to 24^h, December 25.

A. M. van Wijk, *Officer-in-Charge*

NOTES

(See also pages 32 and 70)

14. *Personalia*—The Council of the American Association for the Advancement of Science on December 30, 1946, elected Dr. *Merle A. Tuve*, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a Vice-President of the Association and Chairman of the Section on Physics for the calendar year 1947.

S. L. Seaton, Associate Physicist, Department of Terrestrial Magnetism of the Carnegie Institution of Washington, resigned January 24, 1947, to accept a position in the Air Material Command, Watson Laboratories, Red Bank, New Jersey.

W. D. Parkinson left Washington, D. C., February 22, 1947, for Ecuador where he collected specimens of magnetized varves for use in connection with researches in progress at the Department of Terrestrial Magnetism. On completion of this work he proceeded to the Huancayo Magnetic Observatory to make special investigations in atmospheric electricity.

Dr. *Ross Gunn*, formerly of the Naval Research Laboratory, was recently made Director of the new Division of Physical Research of the United States Weather Bureau.

Kenneth A. Norton has been made Chief of the recently-established Frequency Utilization Research Section of the Central Radio Propagation Laboratory, National Bureau of Standards. Mr. Norton rejoined the Bureau from the War Department where he served during the war as consultant in radio propagation to the Chief Signal Officer and assistant director of W. L. Everitt's Operational Research Group.

Lt. *Charles A. Schoene* and Dr. *H. Herbert Howe* of the United States Coast and Geodetic Survey are members of the Navy Antarctic Expedition. They operated a magnetograph and obtained some ground observations with a magnetometer, in cooperation with the work of Navy observers.

Joel B. Campbell, Geophysicist of the United States Coast and Geodetic Survey, has again taken charge of the Sitka Magnetic Observatory.

C. E. Westerman, Geophysicist of the United States Coast and Geodetic Survey, has reported for duty at the Washington office after a period of duty at the Tucson Observatory.

James H. Baden, Jr., Geophysicist of the United States Coast and Geodetic Survey, will make magnetic observations in several South American countries in the first half of 1947.

Samuel G. Townshend retired from active duty on January 1, 1947, after more than 44 years of service as Magnetic Observer with the United States Coast and Geodetic Survey. Most of this time was spent at the Cheltenham Observatory. On January 10 about 50 of his friends from the

Coast and Geodetic Survey and the Carnegie Institution of Washington gathered at Cheltenham to congratulate him and to express their good wishes. A radio and a handsomely decorated scroll were presented to him as material tokens of appreciation for his loyalty and devotion to the work of the Observatory.

Dr. *Gerhard Krumbach* has been appointed Director of the Central Institute for Earthquake Research at Jena, Germany. He requests that publications bearing on theoretical and applied geophysics and related investigations be sent him for the use of his Institute (Fröbelstieg 3, Jena, Germany).

Dr. *Victor F. Hess*, Professor of Physics at Fordham University, was awarded an honorary degree of Doctor of Science at Fordham University, November 17, 1946. It is expected that he will go to the University of Innsbruck in 1948 for one semester as visiting professor.

Professor *Paul Langevin*, Director of the Ecole de Physique et Chimie Industrielle, Paris, died on December 19, 1946, aged seventy-four. He was widely known for his extensive contributions to the subject of ions and ionization, one of which was the discovery of the large ion of the atmosphere.

Brigadier *H. St. J. L. Winterbotham*, C.B., C.M.G., D.S.O., formerly Director-General of the Ordnance Survey, and recently General Secretary of the International Union of Geodesy and Geophysics, died on December 10, aged 68.

We regret to learn from *Nature* [**159**, 19 (1947)] of the death of Professor *Johann Georg Koenigsberger*, 33 Wildtalstrasse, Freiburg i. Breisgau (17B), French Zone, Germany, in his seventy-first year. Koenigsberger was well known for his work on the magnetic properties of minerals, and at the time of his death he was in communication with physicists in England with regard to the publication of a paper which he submitted in 1939 and which was held up during the War; the paper was concerned with changes of coercivity with grain-size. Koenigsberger was suspended from his chair in 1933 and dismissed from the University of Freiburg i. Breisgau in 1934 for having been republican deputy to the Diet of Baden and because of his partly Jewish ancestry. His daughter went to Britain in 1935 and served in the A.T.S. during the Second World War. Koenigsberger was reinstated as Professor at the close of hostilities and carried on theoretical research work under difficulties until the time of his death.

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DUAL LAWS OF THE COURSE OF MAGNETIC DISTURBANCES AND THE NATURE OF MEAN REGULAR VARIATIONS

BY A. P. NIKOLSKY

Abstract—The investigation of magnetic storms by the data of the observatories located in high latitudes has revealed at a number of stations the presence of two maxima in the diurnal variation of magnetic disturbance. The study of a vast material, in particular the magnetic observations at Tikhaya Bay for nine years, has shown the changes of magnetic disturbance in the morning and the night hours to depend on different laws. This, in its turn, gave reasons to suggest that the magnetic disturbances in the morning and the night are of different nature. The above conclusion has proved to be of great importance for the further investigation of the diurnal variations of the disturbed magnetic field in high latitudes.

Moreover, one has scrutinized in detail the connection between the intensity of accidental irregular fluctuations of the magnetic field (D_i), during magnetic storms and the corresponding absolute values of the horizontal component. According to the data at Tikhaya Bay, the correlation-coefficient between these phenomena was found to be high, $r = -0.70 \pm 0.04$.

The further investigation of the disturbed magnetic field in the same direction, from data at Tikhaya Bay, has shown that the absolute values of the horizontal component for individual quiet hours, selected from the disturbed days, are exactly the same as those on the quietest days. The reduction of the magnetic data for Dickson and Wellen has confirmed the results obtained above. This result cannot be explained from the point of view of our notions on the nature of the phenomena of S_d and D_{st} in the field of magnetic storms.

The result of the present investigation permits the suggestion that during magnetic storms there are only accidental discrete and short-period disturbed magnetic fields caused directly by the corpuscular streams coming from the Sun. The mean, regular variations S_d and D_{st} in the disturbed magnetic field do not correspond to any real, prolonged phenomena in the field of magnetic storms and are fictitious, that is, merely statistical results.

§1. The magnetic field of the Earth is sometimes subject to very strong and rapid changes. This phenomenon has been named magnetic storms or magnetic disturbances. These are especially frequent and intense in the Arctic and the Antarctic Zones.

The examination of the magnetograms has shown the magnetic disturbances to be a sequence of short-period, accidental, irregular, intense,

and rapid variations of the magnetic field. Whence, the course of magnetic disturbances is remarkable for great complexity and chaotic character.

Simple means taken from the data of observations for a large number of magnetic storms revealed regular mean variations, that is, some average peculiarities taking place in the course of magnetic storms. Therefore an observed disturbed magnetic field has been assumed to represent a total of several disturbed fields, each of which is due to its own causes. Such regular mean variations are: The daily variation on disturbed days (S_d) and the storm-time variation (D_{st}); in high latitudes S_d nearly coincides with the disturbance-daily variation (S_D).

These regular mean variations in the disturbed field are distorted in each given magnetic storm by accidental local irregular changes of magnetic field (D_i). It should be also noted that the variation-range of magnetic elements in the random oscillations of the field (D_i), and especially in high latitudes, is sometimes ten and more times as large as that of S_d. The accidental variations of the field (D_i) are smoothed in computing S_d and D_{st}.

The regular variations of the disturbed magnetic field are usually considered to be the result of some systems of electric currents in the high atmospheric strata, arising with the beginning of a storm.

Accidental irregular changes of magnetic field during the magnetic storms (D_i) are considered to be the direct consequence of the corpuscular streams emitted by the Sun.

It would not be an exaggeration to say that until recently most attention was paid to the investigation of mean regular variations of the disturbed field while the accidental, short-period, appreciable variations of the field were studied but very little in spite of their being the main peculiarity in the course of each individual magnetic storm.

The corpuscular radiation of the Sun, because of the magnetic field of the Earth, is deflected to the region of its high latitudes and directed chiefly to the zones of maximum frequency and intensity of aurorae polaris, which are therefore the regions of maximum magnetic disturbances too. The latter circumstance gives reason to suppose that the study of magnetic disturbances in high latitudes may prove quite promising although their character here is especially complicated.

The results of observations of magnetic observatories situated in the Arctic regions of the USSR and usually covering in their work a period of ten years and more, yield valuable material for an investigation of magnetic storms.

§2. The intensity of accidental and irregular changes of the magnetic field during magnetic storms is the characteristic of the magnetic disturbance or the magnetic activity. The magnetic disturbance, for instance, within an hour's interval, can be easily characterized by some numerical indices.

One of them, for example, the international characteristic C with the scale 0, 1, and 2 is based on the numerical subjective estimate of disturbance. Others, such as, say, characteristic K-indices suggested by Bartels [see 1 of "References" at end of paper] base the estimate of disturbance on the objective measurements.

The direct examination of magnetograms proves the probability of the appearance of fairly pronounced magnetic disturbance of the given station within one day to be different, that is, a quite definite (on the average) diurnal variation of magnetic disturbance is present there. It is of great interest that the shape of the curve of the mean diurnal variation of magnetic disturbance, especially in high latitudes, is subject to appreciable variations due to the geographical position of the station, season, general disturbance, etc.

The results of Bartels [1], Davies [6], Chree [5], Kalitina [16], Kosuchina [17], Crichton Mitchell [9], Nikolsky [18], Schmidt [10], Stagg [11], and others give the first general idea of the diurnal variation of magnetic disturbance both in low and in high latitudes.

Our information on the diurnal variation of magnetic disturbance in high latitudes has greatly increased since the reduction of the observations of the Second International Polar Year 1932-1933 was completed.

All these investigations have shown that the main peculiarity of the mean diurnal variation of magnetic disturbance in high latitudes consists in the fact that at some stations this variation has two maxima instead of the usual single, more-or-less intense night maximum of disturbance, the second maximum taking place in the morning hours or before noon.

Stagg [11], basing his discussion on the analysis of the observations of ten magnetic observatories, suggested a general scheme of the geographic distribution of the diurnal variation of magnetic disturbance in high latitudes. Of ten stations, considered by Stagg, three were in the Antarctic Zone, two—in rather south latitudes of the Northern Hemisphere—and only five stations in high latitudes of the Arctic Zone, four of them being located in northern Canada and in Greenland. In such a way, with the exception of Sodankylä, Stagg's investigation did not represent at all the high latitudes of Arctic regions of the Eastern Hemisphere.

The scheme of the geographical distribution of the diurnal variation of magnetic disturbance, suggested by Stagg is based on the following principles:

(A) According to the curve of the diurnal variation of disturbance, the whole region of high geomagnetic latitudes can be divided into three zones concentric with the pole of uniform magnetization: (a) The external zone, below $\varphi_m = 69°$ to $70°$ is characterized by the diurnal variation of magnetic disturbance with one maximum before midnight, the morning and the noon hours being quiet; (b) on the contrary the internal zone from

$\varphi_m = 78°$ to $\varphi_m = 90°$ is characterized by the diurnal variation with the maximum in the morning or even at noon while the night maximum of disturbance, if any, is scarcely noticeable and that only in winter; (*c*) finally, the transitional zone, from $\varphi_m = 70°$ to $\varphi_m = 78°$, has the diurnal variation of disturbance marked by two maxima, the morning and the night ones.

(*B*) Below the geomagnetic latitude 69°-70° the shape of the curve depends neither on season nor on the general intensity of the magnetic disturbance.

(*C*) The diurnal variation of magnetic disturbance is controlled by local time.

§3. The magnetic observatories organized by the Arctic Research Institute of USSR at Calm (Tikhaya) Bay, Dickson, Chelyuskin, Wellen, and Tixi Bay, supplied new data, which in combination with the other material available permitted the investigation of the problem of the geographic distribution of the diurnal variation of magnetic disturbance based on the results of observations of a greater number of uniformly distributed stations than Stagg had at his disposal.

Moreover, the dependence of the shape and the range of the diurnal variation of disturbance on season, general magnetic disturbance, etc. was also scrutinized. The behavior of magnetic disturbance has been studied in some other respects as well.

The magnetic observatory at Tikhaya Bay, located on Franz Joseph Land ($\varphi = 80°.3$, $\lambda = 52°.8$; $\varphi_m = 71°.5$, $\Lambda = 153°.3$) has been in operation since 1931; that is why its data served as the fundamental material for the investigation in question.

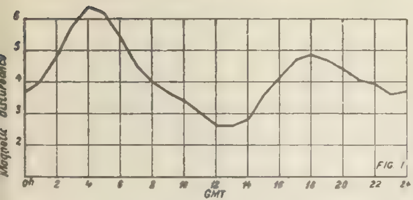
The length of curve of the *D*-variometer was used, as an every-hour characteristic of disturbance proved to be in good agreement with other estimates of disturbance being in common use.

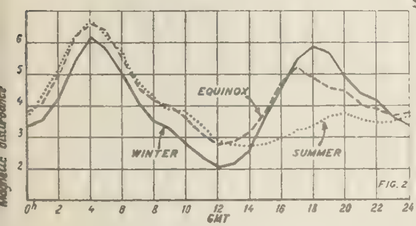
In particular, its mean monthly values agree well with the corresponding values of characteristic *K*. So, for instance, the correlation-coefficient between the mean monthly values of the disturbance-index as adopted by us for the Tikhaya Bay in 1943 and the corresponding values of *K*, as computed by the data of 27 observatories, turned out to be $r = 0.96 \pm 0.02$. This estimate of the hourly magnetic disturbance was used in the reduction of the magnetograms of the Tikhaya Bay Observatory for the period 1934-42.

As a result of this reduction, the mean annual diurnal variation of disturbance in the Tikhaya Bay (Fig. 1) was found to have two distinct maxima, one at 04^h and the other at 18^h GMT (07^h and 22^h LMT.).

Thus judging from the shape of the curve of the diurnal variation of disturbance, Tikhaya Bay, according to Stagg's classification, should be referred to a transitional zone.

Figure 2 represents the mean diurnal variation of disturbance by





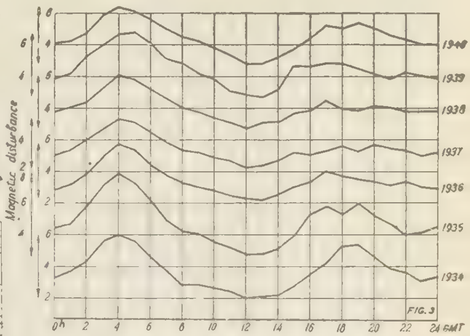


FIG. 1—DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY (MEAN FOR SEVEN YEARS)

FIG. 2—SEASONAL DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY (MEAN FOR SEVEN YEARS)

FIG. 3—DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY FOR INDIVIDUAL YEARS

seasons. It shows that during the morning hours in different seasons the disturbance in Tikhaya Bay changes but little, its maximum for all seasons falling at 04^h GMT. The intensity of night disturbance varies quite appreciably with seasons, and, besides, its maximum shifts from 17^h at equinox to 20^h in summer.

Figures 3, 4, and 5 give the mean diurnal variation of disturbance for separate years—the average for the year, for equinoxes, and for winter. As seen from these figures the phase and the shape of the curve of the diurnal variations in the hours of morning disturbance change very little for individual years, both by seasons and in the average for a year. Contrary to that, those in the hours of night disturbance undergo very great changes. Besides, the night maximum itself very often consists, in this case, of two or even three secondary maxima.

It has been also found that the shape of the curve of the diurnal variation depends on the general intensity of magnetic disturbance. Figure 6 shows the mean diurnal variation of disturbance at Tikhaya Bay for six groups of days with different intensity of disturbance—from the most quiet to the most disturbed ones. In fact, for quiet and inappreciably disturbed days, the morning disturbance prevails all the day. As the general intensity of disturbance increases, the relative value of the night disturbance begins to grow. For great storms the night disturbance becomes equal to the morning one and finally exceeds it.

Sharp differences are observed at Tikhaya Bay in the seasonal variations of the morning and the night magnetic disturbance. Figure 7 shows the seasonal variation of the mean monthly values of disturbance separately both for the morning and the night hours.

To obtain those values means were taken from 01^h to 12^h for the morn-

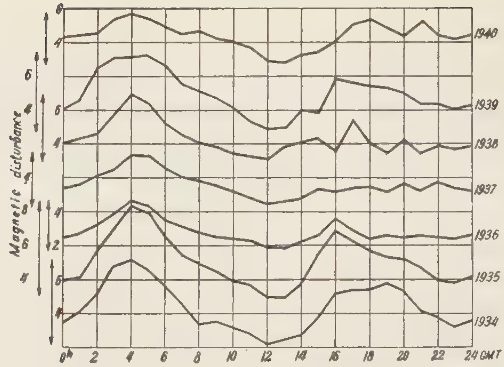


FIG. 4—DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY AT EQUINOXES FOR INDIVIDUAL YEARS

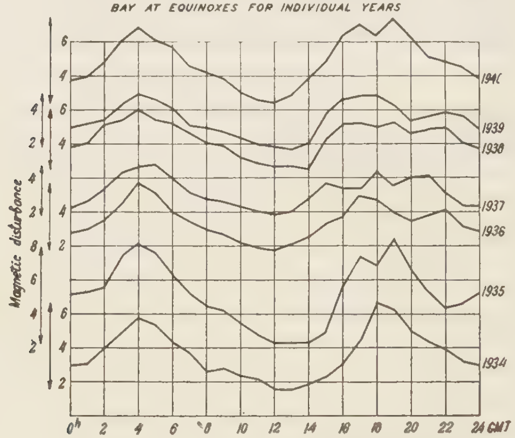
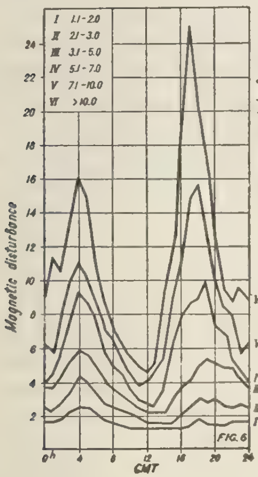


FIG. 5—DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY IN WINTER FOR INDIVIDUAL YEARS

ing and from 13^h to 24^h GMT for the night disturbance in every mean diurnal variation for the month. The examination of Figure 7 proves the seasonal variation of the morning and the night disturbance to be inversely proportional. The general level of the mean values of the morning disturbance is higher than the level of night disturbance, the difference being especially marked for the summer months. The morning disturbance attains its maximum in June and its minimum in November or December. The night disturbance on the contrary, has its maximum in December or February and its minimum in August. Equinoctial maxima are noticeable in the seasonal variation of both the morning and the night disturbance.

Further the problem of the relation of the intensity of both maxima was investigated. For seven years 318 days have shown strong storms, 84 days being marked with the most intense disturbance. For each of 318 days

the mean values for the morning and the night disturbance, from 01^h to 12^h and from 13^h to 24^h GMT, respectively, were computed. Then the correlation-coefficient was calculated between the values of the morning and the night disturbance for all the 318 days. The computations gave $r = 0.57 \pm 0.02$. Provided we compute the correlation-coefficient for the same storms, but separately for summer and winter, its value will turn out to be still smaller.



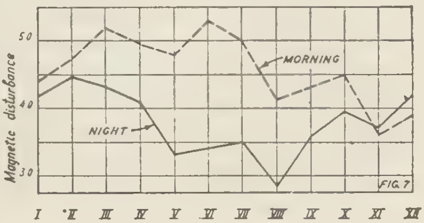


FIG. 6—DEPENDENCE OF SHAPE OF DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY ON GENERAL INTENSITY OF MAGNETIC STORMS

FIG. 7—SEASONAL VARIATION DURING MORNING AND NIGHT OF MAGNETIC DISTURBANCE AT TIKHAYA BAY (MEAN FOR SEVEN YEARS)

The correlation-coefficient between the morning and the night disturbance, in case of the strongest storms, was found to be very small. It means that during the strongest magnetic storms the morning and the night disturbance at Tikhaya Bay show no relation whatever. This is also confirmed by the consideration of individual magnetograms. Moreover, the 27-day diagrams drawn separately for the morning and the night disturbance for the data at Tikhaya Bay, do not decisively coincide one with another, though there is a tendency to the recurrence of intense disturbance over 27 days on each of them. It should be also noted that the maximum in the diurnal variation of aurorae polaris coincides in time with the night maximum of magnetic disturbance. The morning disturbance does not reveal such a connection with the appearance of auroras, although at Tikhaya Bay in the middle of polar night, the morning and the forenoon hours are dark enough to permit seeing even the faintest auroras.

The comparison of the mean diurnal variation of disturbance at Tikhaya Bay with the ionospheric data has shown that the appearance of the intense sporadical E-layer coincides with the night magnetic disturbance.

The results obtained show that the behavior of the morning and the

night magnetic disturbance at Tikhaya Bay differs in more than one respect.

§4. It seemed of interest on the basis of the data available on the diurnal variation of magnetic disturbance in the eastern regions of the Arctic Zone to determine whether these data agree with the scheme of the geographic distribution of the diurnal variation of magnetic disturbance, suggested by Stagg. Besides the data of other stations, some of which were not included in Stagg's investigation, were used by us for the same purpose.

The study of this question by using the observations of 16 high-latitude magnetic stations, uniformly distributed in longitude in the Arctic Zone, has shown that many of these stations do not agree with Stagg's scheme. These discordances are in the fact that the maximum of the morning disturbances for the stations located on the same geomagnetic parallel appear at different hours of the local time. Besides, in the eastern region of the Arctic Zone, the morning maximum appears more to the south (at Ssagastyr, $\varphi_m = 62°$), than it should be for a transitional zone ($\varphi_m > 70°$) according to Stagg.

Thus, the dependence of the time of maximum of the morning disturbance (referred to local time) on geomagnetic latitude exhibits great inconsistencies.

Bartels [1], Kwei [7], and Chree [5] have pointed out the possibility of a component in the diurnal variation of magnetic disturbance developing according to universal time. This suggestion was checked by us with the data at our disposal. Figure 8 represents the dependence of the time of the morning disturbance maximum (referred to GMT) on geomagnetic latitude. As seen from this Figure, all the stations used for this purpose were divided into two groups; one group included all the stations of the Eastern Hemisphere, and the other, the stations of the Western Hemisphere. The scattering of points in both groups is negligible.

In the Eastern Hemisphere, the morning maximum of disturbance takes place at 20^h GMT in geomagnetic latitude $\varphi_m = 60°$. Then, as φ_m increases by 1°, the time of the morning maximum lags by 0.7 to 0.8 hour. In this case it should appear on the pole of uniform magnetization ($\varphi_m = 90°$) at about $16^h.5$ GMT.

In the Western Hemisphere the maximum of the morning disturbance appears almost simultaneously at all the stations and also at $15^h.5$ to $16^h.5$ GMT.

It should be also noted that $16^h.5$ GMT corresponds to the true noon in the meridian of the pole of the uniform magnetization, and thus this moment is not usual with respect to the orientation of the uniform constant magnetic field of the Earth relative to the Sun. As follows from Figure 8, in high latitudes of the Eastern Hemisphere, the maxima of the morning disturbance in the mean diurnal variation on the same geomagnetic parallel take place simultaneously.

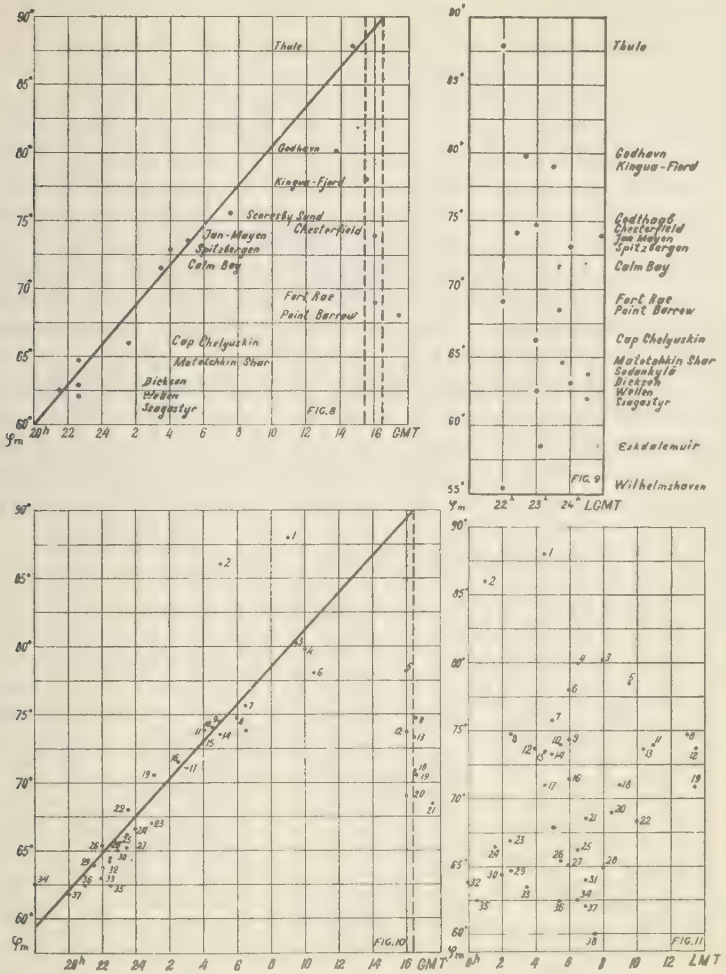


FIG. 8—DEPENDENCE OF APPEARANCE OF MORNING MAXIMUM OF MAGNETIC DISTURBANCE ON GEOMAGNETIC LATITUDE

FIG. 9—DEPENDENCE OF APPEARANCE OF NIGHT MAXIMUM OF MAGNETIC DISTURBANCE ON GEOMAGNETIC LATITUDE

FIG. 10—DEPENDENCE OF APPEARANCE OF MAXIMUM OF EASTERN DECLINATION ON GEOMAGNETIC LATITUDE

FIG. 11—DEPENDENCE OF APPEARANCE OF MAXIMUM OF EASTERN DECLINATION ON GEOMAGNETIC LATITUDE

Such strange difference, as may be seen at first in the dependence of the time of maximum of the morning magnetic disturbance in the Western and Eastern hemispheres on the geomagnetic latitude becomes still more trustworthy if we mention here, that the investigation and the classification of

the behavior of ionospheric layers have also led to the recognition of the necessity of dividing the Earth into three zones [14]. Such zones are the Western Zone, the Eastern Zone, and two Transitional Zones. It is of interest to note, that the boundaries of these zones coincide very closely with those found by us [18] on the basis of the study of geomagnetic disturbance in high latitudes. Figure 9 represents the dependence of the time of maximum of night disturbance, referred to the geomagnetic local time, on geomagnetic latitude. As follows from this Figure, all the points range within an interval of three hours, from 22^h to 01^h. In this way we may conclude, that besides the component elapsing in local time, the diurnal variation of magnetic disturbance contains a component in universal time. This is also confirmed by the difference in the behavior of the morning and the night magnetic disturbance.

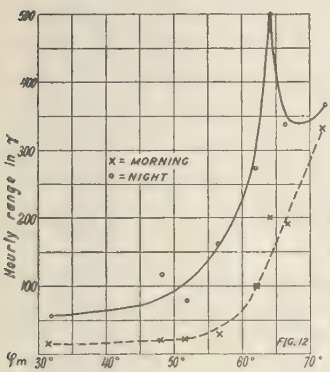
§5. When studying the disturbed magnetic field at high-latitude stations, it was noticed that the moment of the maximum of the morning disturbance coincides with the maximum of the eastern declination. Since the number of stations with known mean diurnal variation of declination is larger than that with the known diurnal variation of disturbance, it

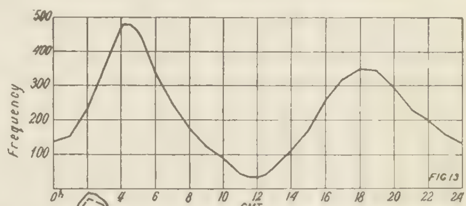
Table 1—*List of high-latitude stations used in investigation*

No.	Station	φ_m	No.	Station	φ_m
		°			°
1	Thule	88.0	21	Point Barrow	68.6
2	Fort Conger	86.7	22	Henrietta's Island	68.0
3	Drifting station *North Pole*	80.2	23	Tromsö	67.1
			24	Bossekop	66.6
4	Godhavn	79.8	25	Cap Chelyuskin	65.9
5	Gjöahavn	77.8	26	Andrea's Island	65.5
6	Kingua Fjord	78.1	27	Nordenskiöld Archipelago	65.2
7	Scoresby Sund	75.8			
8	Godthaab	74.8	28	Nerpalakh Bay	65.0
9	Cap Thordsen	74.5	29	Matotchkin Shar	64.8
10	Sveagruvan	73.9	30	Malye Karmakuly	64.5
11	Drifting station ice breaker *G. Sedov*	74.0	31	Maliy Lyakhovsky Island	63.9
12	Angmagssalik	74.2	32	Sodankylä	63.8
13	Chesterfield Inlet	73.5	33	Dickson	63.0
14	Jan Mayen	73.4	34	Wellen	61.8
15	Hornsund	73.1	35	Kandalaksha	62.5
16	Tikhaya Bay	71.5	36	Ssagastyr	62.2
17	Bear Island	71.1	37	Four Pillar Island	62.0
18	King Point	70.2	38	Sitka	60.0
19	Julianehaab	70.8			
20	Fort Rae	69.0			

seemed interesting to investigate the dependence of the time of maximum of the eastern declination, in its diurnal variation, on geomagnetic latitude. Figure 10 gives the dependence of the time of maximum of the eastern declination in the mean diurnal variation, referred to Greenwich time on geomagnetic latitude, as found by Fedchenko [20] by the data of 38 high-latitude stations. The list of the stations used for plotting the graph is given in Table 1.

For the sake of comparison, Figure 11 shows the dependence of the time of maximum of the eastern declination on geomagnetic latitude, but referred to local time. As seen from this Figure, the scattering of points for Greenwich time is much less than in those instances when the data are arranged by local time. On Figure 11 we have a whole cluster of points and any dependence here is out of question. Since Figure 10 displays a close similarity to Figure 8, it is possible to suppose that the morning disturbance is present, to some degree, at all 38 stations, although at some of them it appears so early, as to overlap with the night disturbance and thus will not emerge in the mean diurnal variation of disturbance.





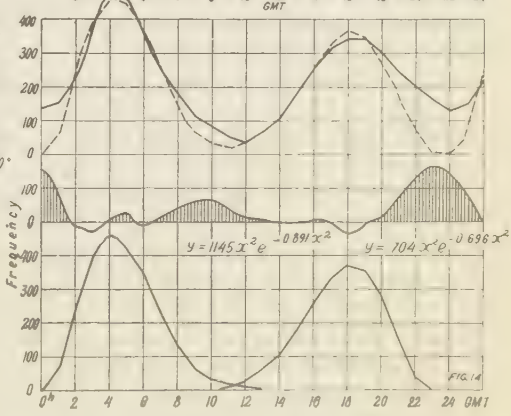


FIG. 12—DEPENDENCE OF INTENSITY OF MORNING AND NIGHT MAGNETIC DISTURBANCE ON GEOMAGNETIC LATITUDE

FIG. 13—DISTRIBUTION-CURVE OF APPEARANCE OF INTENSE MAGNETIC DISTURBANCE AT TIKHAYA BAY DURING THE DAY

FIG. 14—AGREEMENT BETWEEN OBSERVED AND COMPUTED DISTRIBUTION-CURVES OF APPEARANCE OF INTENSE MAGNETIC DISTURBANCE AT TIKHAYA BAY

As has been shown by Stagg [12] the magnetic disturbance has its maximum in the region of the zone of maximum frequency and intensity of aurorae polaris. The study of this question by Gnevishev [15] for the

morning and the night hours separately has shown that the intensity of the morning disturbance grows from $\varphi_m = 50°$ to $60°$ to φ_m close to $90°$, while the night disturbance has a sharp maximum in the zone of maximum auroras. The results obtained are given in Figure 12.

The above considerations permit one to conclude that the behavior of the morning and the night disturbance of magnetic field is very different in many respects or, in other words, this behavior is subject to dual laws. It can be also inferred that the magnetic disturbances in high latitudes in the morning and the night hours are due to different causes. The idea that the corpuscular radiation of the Sun is the main cause of magnetic disturbance is, at present, beyond any reasonable doubt. Therefore it will be truer if we say that the magnetic disturbances in the morning and the night hours are probably called forth by various agents (perhaps particles of different signs) of solar corpuscular radiation. The hypothesis of the unmonochromatic composition of the corpuscular radiation of the Sun has been already suggested more than once, for instance, by Lindeman [8] and by Chapman [4].

For all our further investigations of the disturbed magnetic field it is of importance that each of the two corpuscular agents stimulates the magnetic disturbance not in the course of the whole day, but only during certain hours, quite definite for each station. So, for instance, at Tikhaya Bay, the corpuscular agent responsible for the morning disturbance, can act only from about 23^h–24^h to 13^h–14^h GMT (02^h–03^h to 16^h–18^h LMT). Another agent, causing the evening and the night disturbance acts from 10^h–13^h to 00^h–01^h GMT (from 13^h–16^h to 03^h–04^h LMT). About 13^h–18^h and 02^h–04^h local time, the magnetic disturbances at Tikhaya Bay can be due to both the former and the latter agents.

At other stations the hours (local time) of the agent's effect, causing the morning disturbance can, naturally, be different from the case at Tikhaya Bay, since this disturbance is controlled by universal time (see Figure 8), while the hours of the agent's effect, causing the night disturbance will remain the same. This circumstance, of course, will first of all depend upon the shape of the curves of the mean diurnal variation of disturbance, and second on the fact that the distance between the maximum morning and night disturbance will vary. This, in particular, serves to explain the question why the diurnal variation of disturbance at Dickson and Matotchkin Shar has, at first glance, one prolonged night maximum, while at Chelyuskin and Ssagastyr the morning maximum is quite distinct.

Let us note that to the eastward from Tikhaya Bay the maximum of the morning disturbance should shift to still later hours of local time, which was corroborated by the observations during the drift of the ice-breaker *G. Sedov* [19]. To the westward from Tikhaya Bay the maximum of the morning disturbance, on the contrary, is shifted to still earlier hours of local

time, overlaps with the night maximum, and on the average gives one prolonged night maximum, which is observed, for instance, at Jan-Mayen [18].

It should be noted that some of the above revealed regularities, confirming the dual behavior of magnetic disturbance, have been obtained by the observations at Tikhaya Bay only. The question arises how far the conclusions drawn from the data of a single station are reliable?

The Tikhaya Bay Observatory possesses an extremely favorable peculiarity in the course of magnetic disturbances, which makes it especially interesting for the investigation of magnetic storms. This peculiarity is that (see Fig. 1) at Tikhaya Bay the morning and the night maxima of disturbance are further apart than at any other station for which the observations of many years are available. Thus, if the morning and the night magnetic disturbances are really called forth by different physical causes, the investigation of this question by the data at Tikhaya Bay is especially interesting and trustworthy inasmuch as both of these phenomena in the diurnal variation of magnetic disturbance are revealed here in the purest and least disguised form.

In this way, provided the conclusions on the progress of magnetic disturbance in high latitudes are true, the mean diurnal variation of magnetic disturbance cannot any longer be considered as a periodic phenomenon in the common sense of this word.

§6. On the basis of the conclusions made in the preceding paragraphs and also taking into account the character of the progress of individual magnetic storms, it should be pointed out that in studying the magnetic disturbances one should not only consider the mean diurnal variations of disturbance, but should also take account of the distribution-curves, that is, of the probability of appearance of magnetic disturbance of different intensity during the day.

To study the distribution-curves of magnetic disturbance of different indices at Tikhaya Bay within the day, about 80,000 values of disturbance for every hour of the observations during 1934–42 were used.

Because of lack of space, we shall not dwell here upon the distribution during the day of weak and moderate disturbance, but pass to the distribution of strong magnetic disturbances.

This distribution is represented by Figure 13, which shows that the greatest probability of strong disturbances falls at 04^h and 18^h GMT. Besides, there are periods during the day in which the probability of strong morning and night disturbance considerably decreases and, on the other hand, slight overlapping takes place. Such periods at Tikhaya Bay are the hours from 10^h to 15^h and from 23^h to 01^h GMT. In drawing these curves many values were used. That is why the element of accident in their formation is almost excluded.

It seems quite improbable that the derived distribution of strong disturbances, as a function of the time of the day, may be independent of certain physical causes. It is also confirmed by the fact that the curves obtained in morning and evening hours appreciably deviate from the curve of normal distribution of accidental events (Hauss's curve), symmetrical with respect to its maximum. This difference is especially marked for the morning hours and is manifested in the steep rise of the curve to its maximum from 00^h to 04^h and its smooth descent from 04^h to 12^h. Further investigation has shown that the distribution-curves obtained both for the morning and the night disturbance are well described by the empirical equation of the form $y = Ax^2e^{-ax^2}$. The degree of agreement of the computed and observed curves is seen in Figure 14. The largest deviations are due to the fact that in these hours the disturbance may be called forth by the causes giving rise to both the morning and the night disturbances.

It is known, that Maxwell's law of velocity-distribution, which is also valid for the distribution of the velocity of electrons emitted by the red-hot metal, is expressed by the equation of the same form.

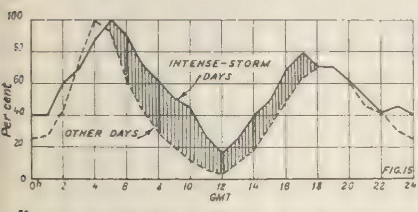
Since the corpuscular radiation of the Sun is the principal cause of magnetic disturbances we have suggested that the moment of the appearance of strong magnetic disturbance both in the morning and the night hours can be determined by the velocity of the corpuscules penetrating the atmosphere of the Earth. As follows from Figure 14 the velocity of corpuscules responsible for the morning disturbance should be the larger the later the disturbance takes place; on the contrary, the velocity of corpuscules causing the night disturbance is the larger, the earlier the latter appears.

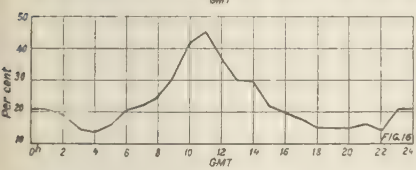
The investigation has shown that there are some additional reasons in favor of the suggestion in question.

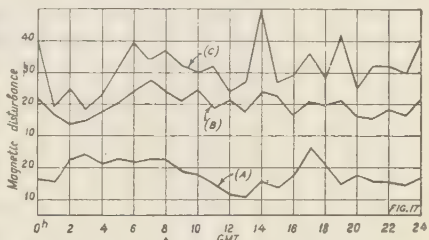
It is known that during strong world magnetic storms, the zone of maximum intensity of aurora polaris and magnetic disturbances descends to more southern latitudes. It follows from Störmer's theoretical calculations that the solar corpuscles deviate more from the poles, the greater their velocities. Consequently, in corpuscular streams, causing strong world magnetic storms and auroras in more southern latitudes than usual, the number of corpuscles with higher velocities should be larger than in common average corpuscular stream. In this connection the question arose, namely, how and in what degree will be manifested the increase of the number of more energetic corpuscles in an average corpuscular stream, for example, at Tikhaya Bay, as it is beyond doubt that these changes in the structure of streams cannot leave unaffected any high-latitude station.

To answer this question a special investigation was undertaken. All the days for the period of seven years were divided into two groups, one group including the days with strong magnetic storms and the other all the

residual days. Then, for both groups and for every day, the number of cases was counted when the magnetic disturbance was evaluated by the index not less than 10 (in the adopted scale index 10 corresponds to strong magnetic disturbance). To have comparable values in plotting the graphs, the maximum number of cases in morning hours for both groups was adopted equal to 100 per cent. The values for all the other hours were expressed in per cent of these maximum values. The data obtained in this way are given in Figure 15. The full curve corresponds to the distribution







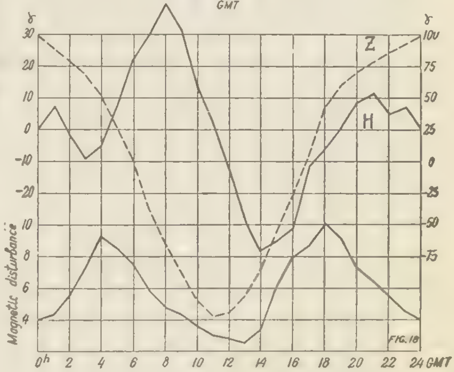


FIG. 15—DISTRIBUTION-CURVE OF APPEARANCE OF STRONG MAGNETIC DISTURBANCE AT TIKHAYA BAY ON DAYS WITH INTENSE MAGNETIC STORMS AND ON OTHER DAYS

FIG. 16—RATIO OF NUMBER OF CASES OF APPEARANCE OF INTENSE DISTURBANCES ON DAYS OF MAGNETIC STORMS TO NUMBER OF CASES ON ALL DAYS

FIG. 17—DIURNAL VARIATION OF MAGNETIC DISTURBANCE AT TIKHAYA BAY FOR (A) 20 INTENSE MAGNETIC STORMS, (B) 5 STRONGEST STORMS, AND (C) STRONGEST STORM, MARCH 1, 1941

FIG. 18—COMPARISON OF DIURNAL VARIATION OF MAGNETIC DISTURBANCE WITH THAT OF H AND Z ON DISTURBED DAYS

of indices $\geq$ 10 for days of strong storms and the dotted one to the distribution on all the other days. This Figure exhibits a clear distinction between these two curves in that the portion of disturbance indices ≥ 10, falling in the interval from 04^h to 18^h is larger for strong magnetic storms than for the other days. Thus, there takes place a shift of the distribution-curves for the morning disturbance towards later hours and for the night one towards earlier hours, that is, both parts of diurnal curve are shifted to 11^h GMT. This phenomenon can be also considered as one of the dual laws in the course of the morning and the night disturbances.

The same data can be represented in a different but not less explicit form. We can set ourselves the question: What number of cases will be in every hour of the day, when the magnetic disturbance was ascribed index

≥ 10 for strong magnetic storms, from the general number of these indices at a given hour for all the days? This is obtained as a ratio of the number of cases on disturbed days to that on all the days and is given in per cent for every hour. Figure 16 shows that this portion is the larger the nearer we are to 11^h when it attains its maximum.

This also indicates that in case of strong and the strongest magnetic storms, observed at Tikhaya Bay, when the corpuscular streams contain the largest number of especially energetic particles, one can expect that strong magnetic disturbance will fill all the interval from 04^h to 18^h, generally free from strong disturbances. Such a phenomenon is really observed. Figure 17 gives: (*a*) The mean diurnal variation of magnetic disturbance at Tikhaya Bay for 20 strong storms; (*b*) the mean diurnal variation for five strongest storms; and (*c*) the diurnal variation of disturbance for the strongest magnetic storm of all so far observed at Tikhaya Bay (March 1, 1941). As seen from Figure 17, for the strongest magnetic storms the diurnal variation of disturbance at Tikhaya Bay is expressed very poorly. It is of interest to note that on curves (*b*) and (*c*) 03^h to 04^h are marked by the minimum of disturbance instead of the usual maximum, that is, the morning disturbance is shifted to later hours.

Thus, the above additional considerations give reason to believe that the coincidence of the distribution-curves of strong magnetic disturbance in the morning and evening hours, with the curve expressing Maxwell's velocity-distribution law is not accidental, but rather has a definite physical sense, and that the appearance of magnetic disturbance at that or other time depends on the velocity of corpuscules.

§7. It is common to believe the mean regular variations in the disturbed magnetic field (S_d and D_{st}) to be the result of some systems of electric currents in the upper layers of the atmosphere arising with the beginning of the magnetic storm. In each given magnetic storm, the course of these regular variations on a disturbed day is distorted by accidental local changes of the field. It may also seem favorable to this notion that the diurnal variation of magnetic disturbance has, in its form, very little in common with the diurnal variation of magnetic elements on disturbed days. This is well illustrated by the observational data at Tikhaya Bay, which are represented in Figure 18, showing the mean diurnal variation of magnetic disturbance and the diurnal variation of H and Z on the disturbed days. Different as the shape of these curves is, it really gives no reasons to suppose that both of these phenomena in a disturbed field result from the progress of the same physical process.

By Chapman's research [3] the relation between these two phenomena in the disturbed magnetic field consists of the following: With the increasing of magnetic storm-intensity curve diurnal variation of magnetic elements changes only its amplitude but not its form. Supposing our assumption of

the disturbance in the morning and the night hours as due to different causes, to be true, we may insist that all the cases where disturbance is ≥ 10, used for plotting the distribution-curves (Fig. 13) for the morning hours, are due to one cause and those for the night hours, to another one. This circumstance can be used for establishing a dependence between the intensity of disturbance and the magnitude of the disturbed field itself in more detail.

With this end in view the proper absolute values of the horizontal component were selected for those hours which were used in plotting the distribution-curves (Fig. 13). All the values referring to the same hour were summed. The total obtained was divided into the number of cases at the given hour. As a result, the mean values of the horizontal component were obtained for those cases (hours) when the magnetic disturbance was estimated by the index not less than 10. Such a mean value was computed for every hour of the day. These means about 04^h–05^h and 18^h–19^h were computed from 200 to 250 values, while at 11^h–12^h the number of cases totaled 5 to 8 only. These mean values of the horizontal component were, naturally, derived from the values of the field of different magnitude and different probability of the appearance; but this is of no importance for the problem we are interested in, although it is worth studying for general reasons.

The variation of mean intensity of the horizontal component, as a function of time, is given in Figure 19. The result presented graphically on this Figure proved to be unexpected and interesting, judging by the deductions which can be drawn from it.

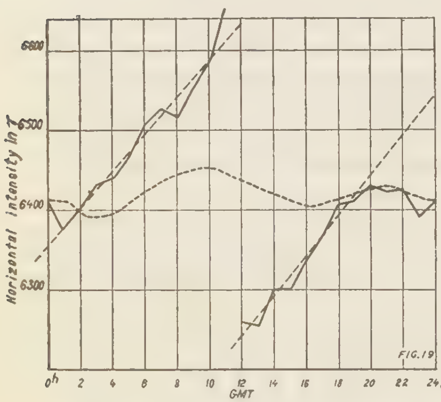
It was found that the later the magnetic disturbance with index ≥ 10 appears in the morning hours, the larger, on the average, are the values of the horizontal component accompanying it, the increase ranging from 6380 to 6650 γ. For the period of the night disturbance, on the contrary, the earlier the night disturbance, the less the values of the horizontal component are related with the magnetic disturbance estimated by index ≥ 10, the general decrease ranging from 6420 to 6250 γ. Such a character of the horizontal-component variation results in a sharp break in its value (400 γ) between 11^h and 12^h, the usual hourly change for the nearest hours being 20 γ. These variations, both in the morning and the evening hours are of nearly linear character.

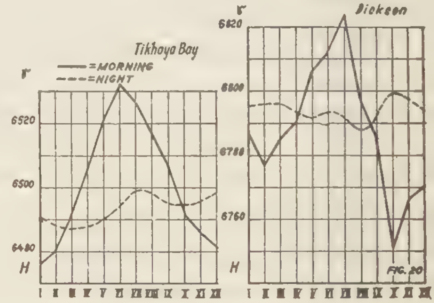
For the sake of brevity, we shall not dwell here in more detail upon the question whether the break of 400 γ in the values of the horizontal component between 11^h and 12^h should be joined in the graph. It should be only kept in mind that the variations of the horizontal component, shown in Figure 19, cannot be taken for a diurnal variation in the usual sense of the word.

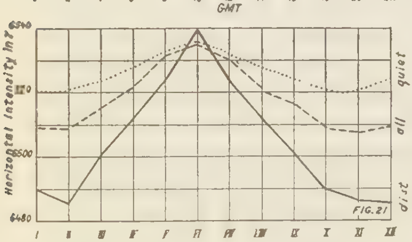
As seen from Figures 2, 3, 4, 5, 6, 13, 15, and 16, the transition from the

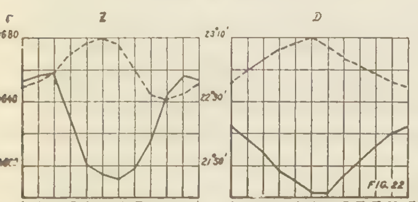
morning to the night disturbance at Tikhaya Bay takes place about 11^h-12^h GMT. Consequently, the fact that the break in the regular variation of the mean values of the horizontal component in Figure 19 falls at the same hours is not accidental, but serves another proof of the previous suggestion on the different nature of the disturbed magnetic field in the morning and night hours.

The result shown in Figure 19 can be considered as a confirmation of the presence of dual laws in the behavior of absolute values of the disturbed magnetic field at Tikhaya Bay. This duality consists in the fact that the magnetic disturbance in the morning and forenoon hours is related to the higher values of the horizontal component, as compared to the mean ones, while the evening magnetic disturbance is related to lower values.









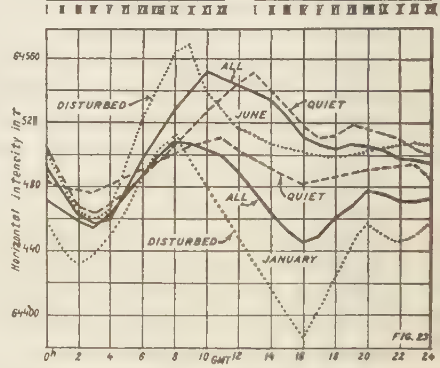


FIG. 19—MEAN CHANGES OF H DURING DAY AT TIKHAYA BAY FOR HOURS MARKED BY INTENSE MAGNETIC DISTURBANCE, AND DIURNAL VARIATION OF H FOR ALL DAYS

FIG. 20—SEASONAL VARIATIONS OF H FOR MORNING AND EVENING HOURS AT TIKHAYA BAY AND DICKSON

FIG. 21—SEASONAL VARIATION OF H AT TIKHAYA BAY ON QUIET, ALL, AND DISTURBED DAYS

FIG. 22—SEASONAL VARIATIONS OF Z AND D FOR MORNING AND EVENING HOURS AT TIKHAYA BAY

FIG. 23—DIURNAL VARIATION OF H (ABSOLUTE VALUES) AT TIKHAYA BAY FOR QUIET, ALL, AND DISTURBED DAYS OF JANUARY AND JUNE (MEAN FOR NINE YEARS)

The highest and the lowest values of the horizontal component occur about 08^h to 11^h and 12^h to 14^h, respectively. This fact is interpretable, if we remember our suggestion on the role of the velocity of corpuscules at the time of appearance of magnetic disturbance. Indeed, just then the magnetic disturbance should be caused by the quickest corpuscules and its value will be the largest or the lowest. Besides, at the same hours one observes the minimum values of Z and of the eastern declination.

The behavior of the curve in Figure 19 within the interval from 20^h to 01^h is evidently due to the fact that at these hours, as follows from the distribution-curve (Fig. 13), the disturbed fields called forth by both causes can occur. As a result of such an overlapping, provided the number of hourly values is sufficient, there will appear in this period of the day the observed variation of the horizontal component.

It is also possible that the result obtained proves the presence of particles of two signs in the corpuscular solar radiation which has been suggested more than once on the basis of purely theoretical considerations.

It was also revealed that the smaller the indices of the disturbance, selected by us as an argument, the less is the growth of the horizontal component in the morning hours and its decrease in the evening ones. Moreover, the probability of fainter disturbances in the interval from 08^h to 16^h being greater than that of strong ones, a mutual overlapping of the influence of the two agents in action will take place during these hours. As a result of it the break, well expressed in Figure 19, will be gradually smoothed. At a large number of any values of disturbed field (all days), we get the usual diurnal variation S_{all}, which is also presented in Figure 19. In addition, from the result of Figure 19 and its discussion, it becomes evident why the difference in the shape of the diurnal variation of magnetic disturbance and the diurnal variation of H and Z takes place on disturbed days (Fig. 18).

Let us use the results obtained for interpreting some facts in the behavior of the magnetic field at Tikhaya Bay. The investigation has shown that the seasonal variation of the horizontal component separately for the morning and the night hours, with the exception of secular variation, is different both at Tikhaya Bay and at Dickson, which is illustrated by Figure 20. The behavior of the curves of the horizontal-component variation agrees with the following: (1) The morning disturbance changes but little with season, whereas the night disturbance varies quite appreciably (Fig. 2); (2) the morning disturbance is responsible for higher values of horizontal component, and the night disturbance for the lowered ones; (3) at Dickson the night magnetic disturbance is more intense than that at Tikhaya Bay

Figure 21 shows the seasonal variation of horizontal component for quiet, all, and disturbed days at Tikhaya Bay, corrected for secular variation. The behavior of the curves on this Figure is evidently due to the

fact that the probability of the appearance of strong night disturbance and, consequently, of the lowered values of the horizontal component, increases from quiet to the disturbed days and from June to the winter months; the morning disturbance and, with it, the higher values of the horizontal component, are less variable and their influence on the seasonal variation of the horizontal component is less pronounced.

The connection between the night (evening) disturbance and the lowering of the horizontal component is clear, in particular, from the fact that the correlation-coefficient by 96 values between the mean monthly values of magnetic disturbance (13^h to 21^h GMT) and the corresponding absolute values of the horizontal component turned out to be $r = -0.70 \pm 0.04$.

The calculation of the seasonal variation for the morning and the night hours separately for the data at Tikhaya Bay was also made for Z and D. The results obtained in Figure 22 show the seasonal variation Z and D to be also different for the morning and the night hours.

Thus, it may be concluded that a disturbed magnetic field, in all its manifestation, is the result of the activity of two different agents of corpuscular solar radiation.

§8. The following investigation was undertaken to determine, in more detail, the connection between the magnetic disturbance and the horizontal component and to try to explain in this way the change of shape and range of the diurnal variation of the horizontal component at Tikhaya Bay as depending on the season and general disturbance, without considering thereby the hypothetical systems of electric currents in the upper layers of the atmosphere.

With this end in view we have used the data for the diurnal variation of the horizontal component at Tikhaya Bay for nine years. The diurnal variations of the horizontal component (means for nine years) have been computed in absolute values for January and June for quiet, all, and disturbed days.

Since, because of secular variation, the mean absolute values of the horizontal component for June are lowered as compared to those for January by 15 γ, all the mean hourly values for June were increased by 15 γ to eliminate secular variation. These diurnal variations of absolute values of the horizontal component are given graphically in Figure 23.

Figure 23 reveals at once peculiarities, which may generally escape attention when the curves of diurnal variations are plotted in their deviations from the mean value, as it is usually done. Figure 23 shows that the changes of the horizontal component in the morning hours are comparatively small at the transition from the quiet days of June to the disturbed days in January, whereas in the evening hours they are considerably larger. Especially remarkable is the very pronounced lowering of the horizontal component in the evening hours on the disturbed days of January and a great increase in the morning hours on the stormy days in June. It

seems also of interest that in the evening hours (from 13^h to 20^h) at the transition from the quiet days in June to the disturbed days of January there takes place, through intermediary groups of days, a regular decrease of the mean hourly values of the horizontal component. The maximum value of the horizontal component and the transition to lowered curves falls at different morning hours. This maximum value appears latest on quiet days in June (13^h) and the earliest on the disturbed days in January (08^h).

In this way six curves of Figure 23 differ considerably both in shape and mean level. Nevertheless a qualitative explanation of changes occurring in the diurnal variations at the transition from one group of days to another can be easily made on the basis of the above results and conclusions. This explanation is based on the suggestion that in high latitudes the mean regular diurnal variation of magnetic elements on disturbed days (S_d) is not due to any additional cause, such as, for instance, a system of electric currents, but is a result of summation of a large number of accidental values of the disturbed field. These accidental values differ as to their magnitude, appear with different probability during the day, and are the magnetic field directly stipulated by the intruding narrow corpuscular streams. Thus we entirely agree with the Birkeland-Störmer viewpoint [2, 13], that the magnetic disturbed field is due to the direct influence of the magnetic field of corpuscules flying from the Sun.

Although this point of view had been previously subjected to serious criticism based on several theoretical considerations, and was consequently rejected, yet the new observational data of high-latitude magnetic observatories prove the expediency of returning to it once more.

In this investigation the following facts were established: (1) The night magnetic disturbance at Tikhaya Bay is strongest in winter and weakest in summer; (2) the morning magnetic disturbance is the most intense in summer and very weak in winter; (3) the morning disturbance is related to the higher values of the horizontal component, the latter being the larger, the greater the disturbance and the later it appears during the day; (4) the night disturbance is connected with the lowered values of the horizontal component being the larger, the greater the disturbance and earlier it appears; (5) with the increase of the general intensity of disturbances the probability of strong disturbance in the interval from 08^h–16^h increases too.

These facts prove sufficient to explain all principal changes occurring in the curves of Figure 23. So, for instance, very high values of the horizontal component on disturbed days of June are caused by a greater probability of strong morning disturbance, bringing in its turn high values of the horizontal component. In the same simple way one can explain great lowering of the horizontal component in the evening hours on disturbed days in January. From quiet days of June to stormy days in January the probability of the appearance of strong night disturbance continually increases

with the increase of the probability of the lowered values of the horizontal component, which fact explains the changes taking place in diurnal variations of the horizontal component in the evening hours. The shift of the maximum of the horizontal component to later hours from the disturbed days of January to the quiet days in June (from 08^h to 13^h, respectively) is due to the probability of the appearance of night disturbance in earlier hours, decreasing from disturbed days of January to quiet days of June.

The variations in the shape and the general level of the curves under consideration are complicated enough to be explained simply by the changes in the hypothetical systems of electric currents in high atmospheric layers. The application of the harmonic analysis to the study of these curves, in view of their complexity, seems to be of little use as well. It will give nothing but the formal representation of these curves in the form of harmonic components.

In this way the changes in the shape of the diurnal-variation curves of the horizontal component, shown in Figure 23, can be explained without the hypothesis of the long-period systems of electric currents.

It was found that the curve of storm-time variation obtained by many authors also does not require for its explanation the hypothesis of the corresponding long-life systems of currents.

The mean effect of the storm-time variation on the horizontal component is known to consist in the lowering of its mean diurnal values. Though the storm-time variation for high latitudes is not determined, yet it is possible to judge of its presence in the disturbed magnetic field in high latitudes by the decrease, at all polar stations, of the mean diurnal values of the horizontal component on the disturbed days as compared with those on the quiet ones.

On the basis of the existing notion of the storm-time variation as of a prolonged phenomenon (of the order of several days), one can suppose that "when a large number of more-or-less disturbed days are considered, each hour of the day will experience approximately the same *mean* storm-time effect D_m" [S. Chapman, "Geomagnetism", 1940, p. 283]. According to this statement, if applied to Tikhaya Bay, the horizontal component, corrected for the diurnal variation S_d, should be, for each hour of the days with magnetic disturbances, on the average, by 30 γ lower than its respective values for the same hours on quiet days. It can be easily proved that such an assumption would not in fact be true.

From the data at Tikhaya Bay for nine years (1934-42) we selected the values of the horizontal component at 15^h–16^h–17^h for those cases, when the magnetic disturbance was estimated by indices 1 and 2, which correspond to absolutely quiet state or nearly so. Such a selection was made separately for the most quiet days, and for days marked with magnetic storms. The selected values of the horizontal components were corrected for

the secular variation and reduced to the beginning of 1934. Then its mean annual value was computed. The total number of values used for the period under consideration was 1700 for quiet and 820 for disturbed days. The results obtained are given in Table 2. Column "Q" contains the values of the horizontal component for 15^h to 17^h on the most quiet days, column "D" for quiet hours on days affected by magnetic storms.

TABLE 2—*Values of H during 15^h to 17^h at Tikhaya Bay, 1934–42, for quiet days and for quiet days affected by magnetic storms*

Year	Q	D
	γ	γ
1934	6583	6584
1935	6583	6580
1936	6582	6579
1937	6576	6576
1938	6584	6581
1939	6585	6586
1940	6594	6587
1941	6587	6582
1942	6604	6599
Mean	6586	6584

Thus, it has been proved that if in the selected hours the magnetic field is quiet, the value of the horizontal component remains unchanged independently of whether these hours occur on the quietest days or on the days affected by magnetic disturbances.

If the values of column "D" are corrected for variation S_d, the values of the horizontal component for quiet hours of the disturbed days will be even larger by 40 γ than the corresponding values on quiet days. The result obtained deviates considerably from the expected difference (Q–D) of 30 γ.

Since individual quiet hours on days with magnetic disturbances, when the horizontal component on the average is close to 6586 γ (Column "Q", Table 2), very often follow directly the strongly disturbed hours with great (to 500 γ and more) decrease of the horizontal component, it is clear that the presence of the afteraction effects (Nachstörung, post-perturbation) in the field of magnetic storms is not to be found here. Similar results are obtained when considering the material for other parts of the day.

The result obtained was checked, in addition to the data for Tikhaya Bay, by those for Dickson and Wellen. Figure 24 gives the diurnal variation of H at Tikhaya Bay, Dickson, and Wellen, for quiet hours selected from disturbed days, for quiet days, and for disturbed days.

The preliminary results of the study of photographic records made at the automatic ionospheric station at Tixi Bay show that no marked effects of afteraction are revealed in the state of the ionosphere during the ionosphero-magnetic disturbances.

In other words, the observational data in high-latitudes confirm the presence during ionospheric disturbance of only short-period, discrete intrusion of the ionizing agent and do not give any indications as to the existence of some anomalous phenomena, which should have taken part in the development of systems of electric currents responsible for S_d.

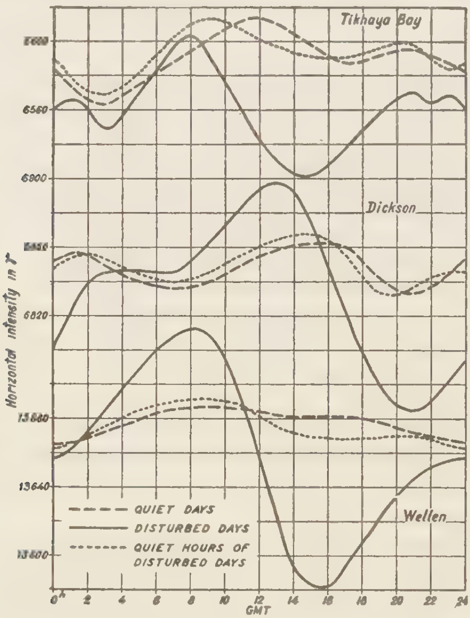


FIG. 24—DIURNAL VARIATION OF H AT TIKHAYA BAY, DICKSON, AND WELLEN FOR QUIET HOURS OF DISTURBED DAYS, FOR QUIET DAYS, AND FOR DISTURBED DAYS

The results obtained show that the disturbed magnetic field in high latitudes is entirely due to the magnetic field directly connected with the corpuscular streams from the Sun intruding into the upper atmospheric layers. It means that, in reality, there are only accidental short-period disturbed magnetic fields different as to magnitude and time of appearance, and that in the field of magnetic storms in high latitudes there exist no other additional long-period and regular phenomena of storm-time variation type (D_{st}) and diurnal variation on disturbed days (S_d).

The interpretation of the formal regular variation-curves D_{st} and S_d, as derived from the statistical summation, can be replaced by another

explanation logically issuing from the results of the present investigation. Indeed, as we have shown above, the intensification of magnetic disturbance in the evening hours is connected with the decrease of the horizontal component, the correlation-coefficient being $r = -0.70 \pm 0.04$; $H = -9.2x + 6600$. For perfectly quiet days $x = 1$, $H = 6590\gamma$ (see column "Q" in Table 2). This fact, together with the results given in Table 2, proves that during the magnetic storms there occur no fluctuations of the magnetic field relative to some mean value of the field (S_d and D_{st}). Accidental values of the disturbed magnetic field are superposed directly on the magnetic field corresponding to perfect calmness, for instance, either only increasing H in morning hours, or only decreasing it in the afternoon hours (Fig. 19).

The growth of the horizontal component, due to the intensification of the morning disturbance, plays no great role at Tikhaya Bay in the formation of mean variations, because the morning disturbance is less variàble than that of the evening hours. At the high-latitude stations, where evening disturbance is of prevailing importance, the principal role in that formation of the mean variation curves is in the decrease of the horizontal component.

In magnetic storms the probability of intense disturbance in the evening hours considerably increases and together with it grows the probability of the appearance and, consequently, the weight, in the statistical total, of the values of the horizontal component for every hour, considerably decreased as compared with quiet days.

When the material is arranged by local time and in absolute values, it appears that the obtained (mean) curve (variation S_d) differs in its shape, range, and general level from the curve for quiet days (variation S_q). When the material is arranged by time of the storm and its mean values are subsequently taken, this procedure brings about a general decrease of the background of the horizontal component as compared to quiet days and takes the form of curve D_{st}.

Finally, it should be noted, that a number of regularities in the behavior of the magnetic field at Tikhaya Bay shows no difference whatever with respect to the corresponding regularities at other, both high-latitude and middle-latitude, stations. This gives reason to believe that all the other conclusions made for Tikhaya Bay only, will prove to be valid for other stations, after some additional scrutiny of their data. It should be kept in mind, however, that Tikhaya Bay has several advantages for settling the problem of the nature of magnetic disturbances: (1) At Tikhaya Bay as a polar station, accidental fluctuations of the field at the time of disturbances are dominating phenomena and are more pronounced than in the middle latitudes; (2) the two maxima in the diurnal variation of magnetic disturbance stand far from one another; (3) Tikhaya Bay observations are available for many years.

Conclusions

(1) A disturbed magnetic field in high latitudes is the result of the effect of two physical causes, independent in their final influence; these causes are two different agents of the corpuscular radiation of the Sun.

(2) Each of these two agents is responsible for magnetic disturbances only at some hours of the day, being quite definite for every station; one of these agents gives rise to the magnetic disturbances in the morning and noon hours and the other in the evening and night hours.

(3) The whole phenomenon of magnetic storms, in all its variability, is nothing but a sequence of accidental discrete, impulsive changes of magnetic field; these accidental changes differ in their magnitude and appear with different probability.

(4) The probability of the appearance of these or other absolute hourly values of disturbed magnetic field and magnetic disturbance of varying intensity depends on the geographical situation of a station, the time of the day, month and season, the general magnetic disturbance, and the order of the year in the eleven-year cycle of solar activity; this, in its turn, determines the form and the absolute values of mean variations of the disturbed magnetic field S_d and D_{st}.

(5) The hourly absolute values of the horizontal component are determined, on the average, only by the degree of magnetic disturbance and are independent of whether these hours occur on disturbed or quiet days. The intensification of the evening disturbance is connected with the decrease of the horizontal component (correlation-coefficient $r = -0.70 \pm 0.04$). All this is to confirm that during the time of magnetic storms no fluctuations of the magnetic field take place with respect to any mean value (S_d or D_{st}). Accidental values of the disturbed field are superposed directly upon the value of the field, corresponding to perfect calmness.

(6) The mean regular peculiarities in the field of disturbance of magnetic storms in high latitudes, namely, the diurnal variation on disturbed days (S_d), storm-time variation (D_{st}), and its mean effect (D_m) represent fictitious, quite statistical results, and have nothing to do with any real, long-period physical phenomena. There is no need to find, for instance, for their explanation any systems of electric currents in the upper atmospheric layers.

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Leningrad, USSR, October, 1946

(See also pages 188, 216, 232, and 263)

PROVISIONAL SUNSPOT-NUMBERS FOR JANUARY TO MARCH, 1947

Day	January	February	March
1	77	64	103
2	62	90	134
3	56	84	106
4	54	90	163
5	47	115	165
6	56	115	198
7	87	111	208
8	93	107	210
9	93	153	212
10	102	162	194
11	120	213	206
12	120	206	164
13	120	193	150
14	151	199	118
15	187	166	92
16	164	157	76
17	193	154	59
18	199	130	46
19	190	110	34
20	183	132	57
21	160	100	85
22	158	100	91
23	157	99	121
24	150	96	115
25	135	127	114
26	110	158	112
27	85	156	130
28	72	130	124
29	64		138
30	68		137
31	84		151
Means........	116.0	132.3	129.8
No. days......	31	28	31

Mean for quarter January to March, 1947: 125.8 (90 days)

Swiss Federal Observatory,
Zurich, Switzerland

M. Waldmeier

TERRESTRIAL INFLUENCES IN THE LUNAR AND SOLAR TIDAL MOTIONS OF THE AIR

By Oliver R. Wulf and Seth B. Nicholson

Tidal motions in the atmosphere have been the subject of much study including both the tide produced by the Moon and also the tide-like motion produced by the Sun in which thermal as well as gravitational effects enter. In discussing the lunar atmospheric tide, Chapman [see 1 of "References" at end of paper], to whom a considerable part of our knowledge of this subject is due, has emphasized the importance of peculiarities that manifest themselves in the behavior of such a relatively simple effect. The lunar effect is simple, in contrast to the solar, because it is purely gravitational in origin, free from direct thermal influences which are important in the latter. Complexities that appear in the lunar tide must apparently be due to the atmosphere itself and its lower boundary, the surface of the Earth.

One of the most intriguing peculiarities of the lunar atmospheric tide is the distribution of its phase with latitude. This is not symmetrical about the equator, the phase in the average being distinctly later in much of the Northern Hemisphere than in the Southern. High tide comes for the most part a little later than lunar transit, the lag being greatest in the vicinity of 25° north latitude where in the annual mean it amounts to about an hour. Figure 1, after Chapman [copied from 1*a*], illustrates these points.

When the data are separated into three groups representing the months around the June solstice, around the December solstice, and around the equinoxes, respectively,* another striking peculiarity is brought out. High tide comes much later in low and middle latitudes during the months of the December solstice than during the other eight months. The period of the June solstice does not differ greatly from the equinoctial period in this characteristic, the distribution of phase in latitude being indeed nearly the same for the two latter groups of months. These features may be seen in Figure 1. The difference of phase between the months of the December solstice and the remainder of the year is a maximum in the vicinity of 30° north latitude where it amounts to more than an hour, high tide for the months of the December solstice coming about two hours after lunar transit.

We believe that this asymmetrical distribution of the phase about the equator and its asymmetrical distribution in time with respect to the seasons is to be largely explained by the difference in resistance to tidal flow of air offered by the surface features of the two hemispheres, the

*Group of the June solstice—May, June, July, and August; that of the December solstice—November, December, January, and February; and that of the equinoxes—March, April, September, and October.

principal effective factors being the distribution of mountain ranges and the relative proportion of land and water. The Northern Hemisphere, because of its bold relief features, offers greater resistance to the air-flow imposed by the tidal action. Furthermore, the much greater proportion of land in this hemisphere leads, through radiative heating and cooling of the surface, to greater mixing of the air, which through transfer of momentum, also permits the surface to maintain a more effective grip on the air in the Northern Hemisphere than in the Southern.

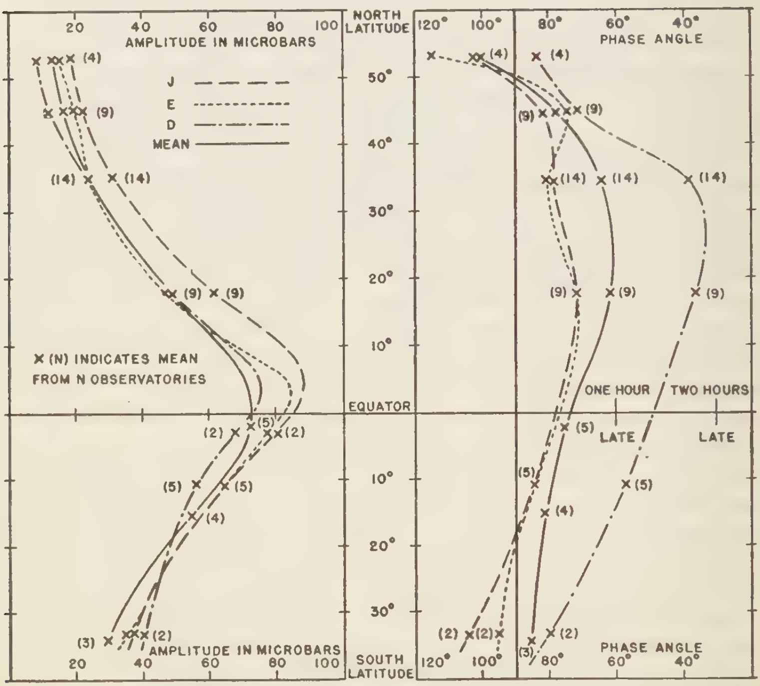

FIG. 1—SMOOTHED LATITUDE-DISTRIBUTION OF AMPLITUDE AND PHASE OF LUNAR ATMOSPHERIC TIDE, ANNUAL AND FOUR-MONTH MEANS (AFTER CHAPMAN)

The lag of the lunar high tide should on this basis be largest in the zone of latitude containing the greatest amount of pronounced relief features in low latitudes where the tidal flow is relatively large. That this is approximately true is strikingly indicated by the data (Fig. 1) which show the lag to be greatest in the vicinity of 25° north latitude. Inspection of a relief map of the world is sufficient to make evident this correspondence. It should be noted that fairly heavily landed zones of the surface of the Earth extend down to the equator.

Moreover, in the winter a greater fraction of the total air over the surface lies below the tops of the mountains than at other times because the lower air of the atmosphere is colder. This factor should be more pronounced in the Northern Hemisphere where large areas of land in the middle latitudes permit important lowering of temperature at and near the surface through radiative cooling in contrast to the Southern Hemisphere where the thermal capacity of the oceans prevents cooling of the lower air to so great an extent. Thus the Northern Hemisphere in its winter offers a greater resistance to the tidal air-flow than the Southern Hemisphere does in its winter. Furthermore, this tidal flow, being a global phenomenon, will be influenced by all of the large-scale movements of the air over the surface of the Earth (both of solar daily character and of circulational character) including some transfer of air across the equator. In this way, through horizontal transfer of momentum, the pronounced resistance to the tidal flow by the low middle latitudes of the Northern Hemisphere is transmitted in a considerable measure to the lower latitudes of the Southern Hemisphere causing the phase of the lunar tide to be latest, in this hemisphere also, during the months of the December solstice. The extent to which this drag reaches into the Southern Hemisphere through transport of momentum should be particularly pronounced during the months of the December solstice when maximum surface temperatures lie to the south of the geographical equator.

Moreover, the extent to which this drag reaches into the Southern Hemisphere will depend also upon a feature of the lunar tide itself which we believe may be of some importance, not alone with respect to the tide, but also because of the coupling it effects in general between the air-motions of the two hemispheres. In the operation of the tide, air must flow over the surface of the Earth, and, in one component of this flow, air will move from higher to lower latitudes and back again. At times when the Moon's declination is large this will involve daily air-flow back and forth between the two hemispheres. The magnitude of the lunar air-tide is small, roughly one-fifteenth that of the solar 12-hour pressure wave [1], but through transfer of momentum from one hemisphere to the other, it seems possible that the lunar air-tide may exercise an important coupling action between the air-motions of the two hemispheres. This action should appear both in the solar daily and large-scale circulational motions, as well as in the average motion of the lunar tide itself, where it thus contributes to the extension into the Southern Hemisphere of the resistance or drag exercised by the surface of the Northern Hemisphere on the tide. In turn this coupling will act to modify the diurnal inequality in the lunar air-tide when the Moon is not over the equator. This inequality has not yet been established in the existing data [1].

A further consequence of the distribution of air due to thermal effects

of the land seems to lie in the behavior of the phase in the Northern Hemisphere during the months of the June solstice and of the equinoxes. The greater relative warming of the lower air due to radiational heating in the land areas of the Northern Hemisphere should raise a greater fraction of the air above the mountain tops and actually diminish the resistance offered to the total air by the heavily landed zone of the Northern Hemisphere. Such an effect may be seen in the data of Figure 1, the phase during the months of the June solstice and of the equinoxes showing a small tendency to be more advanced relative to the annual mean in range 30° to 40° north latitude than somewhat further to the south and north.

Another and somewhat finer detail suggests itself at this point and may deserve attention. It would seem that the phase of the tide should not be quite the same at the autumnal equinox as at the vernal because of a source of resistance that should be strongest following the time of maximum solar radiation incident on land areas. The heating at and near the surface will not only tend to raise the air but will also tend to augment vertical convection and this should in general be somewhat greater following the summer solstice than before it. Vertical stirring constitutes a form of resistance because of the greater grip on the surface that it gives to the air by momentum transfer. The Northern Hemisphere should be dominant in this action and hence it would be following the June solstice that this effect should be most pronounced. Figure 15 [of 1*a*], which has been copied and given here as Figure 2, illustrates the phase and amplitude of the tide for each month derived as the average for three stations. From the

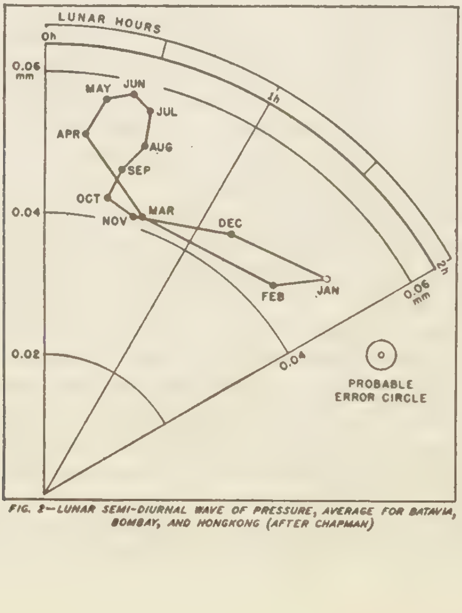

FIG. 2—LUNAR SEMI-DIURNAL WAVE OF PRESSURE, AVERAGE FOR BATAVIA, BOMBAY, AND HONGKONG (AFTER CHAPMAN)

value of the probable error, also shown in the Figure, it appears justifiable to conclude that, in accord with the above, the average phase of the tide at these stations is indeed later for the months that follow the June solstice than for the months that precede.

The relative behavior of the amplitude in the three groups of months also appears to show a certain accord with the explanation suggested above for the behavior of the phase. The amplitude is greater at the June solstice than at the December, the atmosphere being raised to the greatest extent above the surface features and hence most easily distorted by the Moon, at the former time.

If the above considerations are correct it would, of course, be necessary to assert that other air-motions of a similar character should be subject to similar resistance, asymmetric about the equator, and variable with changing season. The other air-motion resembling the lunar air-tide, is the much larger daily motion imposed by the Sun through thermal as well as gravitational action. It is this motion in the upper air that is the origin of the daily variation of the Earth's magnetic field according to the widely accepted "dynamo"-theory of this phenomenon, the variation arising from electric currents induced in the upper electrically-conducting air, as this layer of air, in its daily motion, cuts the lines of force of the Earth's permanent magnetic field. The vortex-like electric currents that flow over both hemispheres and that move with the Sun lead to characteristic traces for the diurnal variation of the three magnetic elements, the forms of which depend chiefly on latitude. The forms of these patterns are of importance to us here only because they afford a means of studying the relative variation of phase of the tide-like air-motion which produces them [2].

In the middle latitudes and indeed over most of a hemisphere, the pattern of the diurnal variation of the declination is particularly simple and useful for this purpose. It consists of a morning easterly maximum and an afternoon easterly minimum, with a point of inflection somewhat before noon. It is, however, not this pattern of the variation which interests us here* but rather the change of phase of this pattern with the seasons. The well-articulated pattern gives simply a convenient reference for observing the change of phase of the air-motion producing it.

The change of phase of the diurnal variation of declination with the season is nicely illustrated by Figure 9 of the publication of the United States Coast and Geodetic Survey [3] entitled "Magnetism of the Earth." This illustration is reproduced in Figure 3. Here for four observatories in the north latitudes 21°, 32°, 39°, and 57°, the diurnal variation on magnetically quiet days is portrayed for the three groups of months discussed above in connection with the lunar tide.

*The actual phase of the pattern depends, of course, on the nature of the air-motion producing it which in this case arises from thermal as well as gravitational effects.

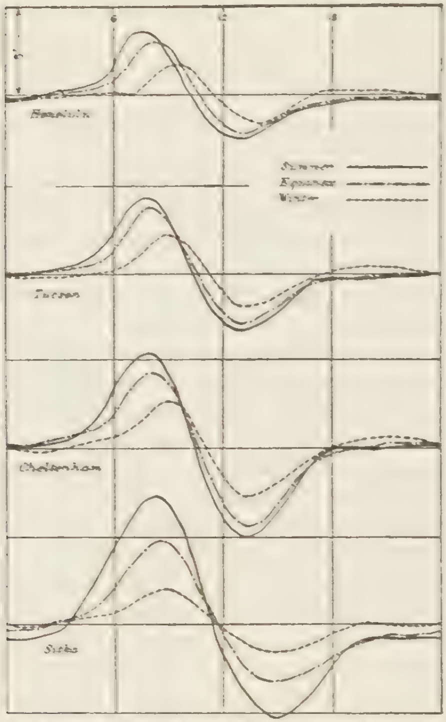

FIG. 3—CURVES SHOWING DIURNAL VARIATION OF DECLINATION

The degree of correspondence of the phase-change with that shown in Figure 1 for the lunar tide is striking. At the two middle-latitude observatories of Tucson and Cheltenham the time of the morning east maximum is nearly the same for the months of the equinoxes as for those of the June solstice, but for the December solstice it is noticeably later, actually about one hour. At the Honolulu Observatory the phase in the equinoctial months is a little later than that in the period of the June solstice, but the phase for the December solstice is later than for the equinoxes by a greater amount. Finally at the Sitka Observatory in high northerly latitude, the phases for the three groups of months, although not exactly the same, show relatively little difference, and that for the months of the December solstice differs least from that for the months of the June solstice among these four observatories.

The extent of the agreement of the annual change of phase in this magnetic effect which arises from a solar-produced daily air-motion, with the annual change of phase illustrated in Figure 1 for the lunar atmospheric tide, strongly suggests that these different air-motions are both affected

by the hemispherically asymmetric resistance to air-flow which the surface of the planet presents. This should be expected if the explanation suggested above for the peculiarities in the phase of the lunar atmospheric tide be correct. The similarity in this behavior in these two effects thus constitutes evidence in support of the explanation. In view of the above it appears important to take into account the remarkable extent of this resistance when considering any air-motion over the surface of the Earth, not alone in its variation with latitude but also in its variation with time of year. The air-motion of greatest magnitude and obvious importance is, of course, the thermally-produced large-scale circulation of the atmosphere. This also should be subject to these same resistance-factors in which radiational cooling and solar heating alter the magnitude of the resistance. The results of recent studies of the annual variation of the monthly average pressure-patterns at 10-km altitude over the United States [4], illustrated in Figure 4, bear some resemblance to the results shown in Figure 2. In Figure 4, as will be clear, we believe, from the text of reference 4, "lateness" or "lag" should probably be interpreted as in the counterclockwise direction,

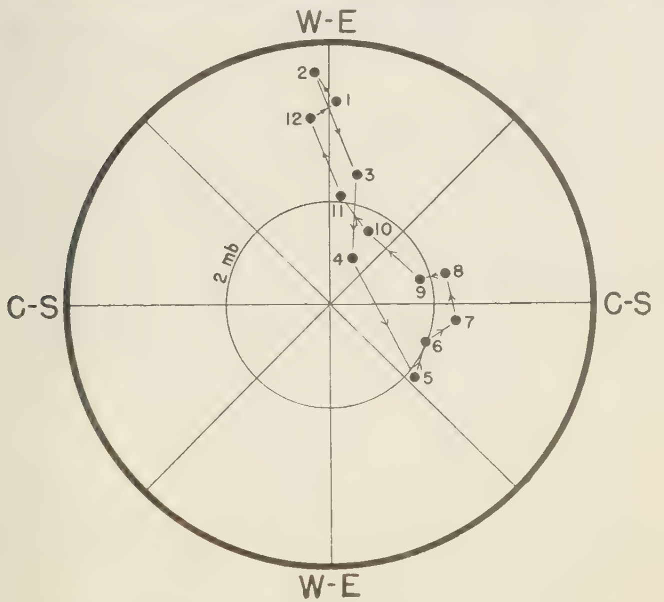

Fig. 4—Annual variation of the pressure-pattern at 10-km altitude over the United States—the twelve point-values of the 3-month overlapping means of the monthly average patterns for 5 years, each point giving the position and amplitude of a pattern [copied from reference 4 (Fig. 36, p. 50) with minor alterations of legend].

opposite to that in Figure 2. Since the two daily air-motions considered above occur in this vigorously circulating and turbulent atmosphere, a mutual dependence through mechanical coupling is certainly suggested. The daily variation of the Earth's magnetic field, being a phenomenon that is continuously and accurately measured at magnetic observatories, would appear to be a promising quantity with which to study this interdependence. Such a study would seem particularly important because the intensity of solar radiation, including, of course, its variability, affects the motion of the conducting air as well as the magnitude of its conductivity.

In closing we venture to hope that investigations along the lines indicated above may demonstrate the soundness of Dr. Chapman's belief "that there is a fair chance of this minute but extraordinary phenomenon [the lunar air-tide] being of value not only in the study of the upper atmosphere, but also of helping to solve the mysteries of the lower levels."

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[1*a*] S. Chapman, Presidential address, Ass'n Met. Washington Assembly, Internat. Union Geodesy and Geophysics (1939).

[1*b*] S. Chapman, The Observatory, **60**, 154-165 (1937).

[1*c*] S. Chapman, Proc. R. Soc., A, **151**, 105-117 (1935).

[2] For the forms of the diurnal variations of the magnetic elements see, for example, S. Chapman and J. Bartels, Geomagnetism, Oxford, Clarendon Press, (1940).

[3] A. K. Ludy and H. H. Howe, Magnetism of the Earth, U. S. Coast Geodetic Surv., Ser. 663, Washington (1945).

[4] O. R. Wulf, M. W. Hodge, and S. J. Obloy, The meteorological conditions in the upper reaches of the radiosonde flights over the United States: I—Pressure, pressure changes, and types of pressure patterns, Misc. Rep., No. 20, Dep. Met., Univers. Chicago, Univers. Chicago Press (1946).

United States Weather Bureau and
Mount Wilson Observatory of Carnegie Institution of Washington,
Pasadena, California, February 24, 1947

A NOMOGRAPH FOR CONVERSION OF FOURIER COEFFICIENTS OCCURRING IN GEOMAGNETIC COMPUTATIONS

By Otto Schneider

Whenever a numerical operation of standard type is to be repeated a great number of times, as often occurs with geomagnetic material of statistical character, the use of nomographs may prove convenient, since it represents a considerable saving of time, provided that the amount of work is large enough to compensate the time of preparing and drawing the nomograph. In the present note, attention is drawn to the practical advantages of this method, widely used in other branches of geophysics and in engineering.

A very simple example is given by the following case, referring to an analysis of S and L at Batavia. In the course of that investigation, a great number of pairs of harmonic coefficients representing diurnal and semi-diurnal variations on individual days had to be transformed in amplitude and phase due to a change, in 1920, of the tabulating scheme adopted by that observatory. Starting with January 1, 1920, hourly *mean values according to standard time* (105° meridian) were published instead of *instantaneous values for local mean time.*[1] Therefore, the harmonic coefficients for days after January 1, 1920, must be reduced in the following way:[2]

24-hour waves—(1) An increase of phase by 5° 40′ (corresponding to 22-1/3 minutes of time), since the first column of tabulated values refers to $00^h\ 30^m$, while in the earlier years, the time origin is at $01^h\ 00^m$, and moreover, local time is advanced by 7-1/3 minutes against 105° meridian time.

(2) Multiplication of amplitudes by the factor $f_1 = 1.0029$ to allow for the smoothing effect introduced when hourly means are used.

12-hour waves—(1) Increase of phases by 11° 20′.

(2) Multiplication of amplitudes by 1.0115.

Thus, the transformed coefficients are as in (1*a*) and (1*b*).

$$A_1^* = f_1(A_1 \cos\varphi + B_1 \sin\varphi) = 0.998\ A_1 + 0.098\ B_1 \ldots\ldots \quad (1a)$$

$$B_1^* = f_1(-A_1 \sin\varphi + B_1 \cos\varphi) = -0.098\ A_1 + 0.998\ B_1 \ldots\ldots (1b)$$

Similar relations hold for the semi-diurnal wave. A nomograph apt for realizing the operations (1*a*) and (1*b*) is easily obtained in the following way.

Let (A), (B), and (A^*) be three parallel scales (Fig. 1) with linear

[1]See Annual report of Batavia Observatory for the year 1920; the data were used for a paper published in this Journal, **46**, 283–300 (1941).

[2]See J. Bartels, Gerl. Beitr. Geophysik, **28**, 1-10 (1930).

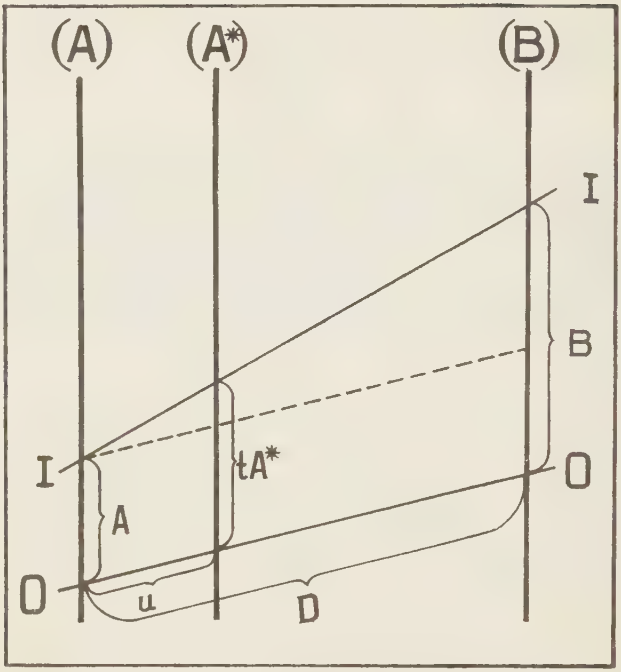

FIG. 1—BASIC SCHEME OF NOMOGRAPH FOR OPERATION OF FORM $A^* = rA + sB$

divisions, the scale-interval being equal to unity on (A) and on (B), and equal to t on (A^*). Thus any point marked A^* on the latter scale will be at a distance tA^* from the origin. The origins of the three scales are supposed to lie in a straight line (0,0), which at the same time serves for characterizing the relative position of the scales, by means of the segments u and D. The segments A, B, and tA^* cut off on the scales by a transversal line (I,I) which passes through any two points marked A and B, are related by (2).

$$A^* = (1/tD)(A(D - u) + Bu) = rA + sB \ldots\ldots\ldots\ldots\ldots (2)$$

Once D is fixed, it is always possible to fit the values of u and t so as to make r and s satisfy any given values, for example, those of the coefficients in (1a). For this purpose, t and u must be chosen as in (3).

$$t = 1/(r + s) \qquad u = D.s/(r + s) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In the same way, a fourth scale (B^*), not reproduced in Figure 1, is obtained, satisfying another pair of values r and s, as given by (1b). (B^*)

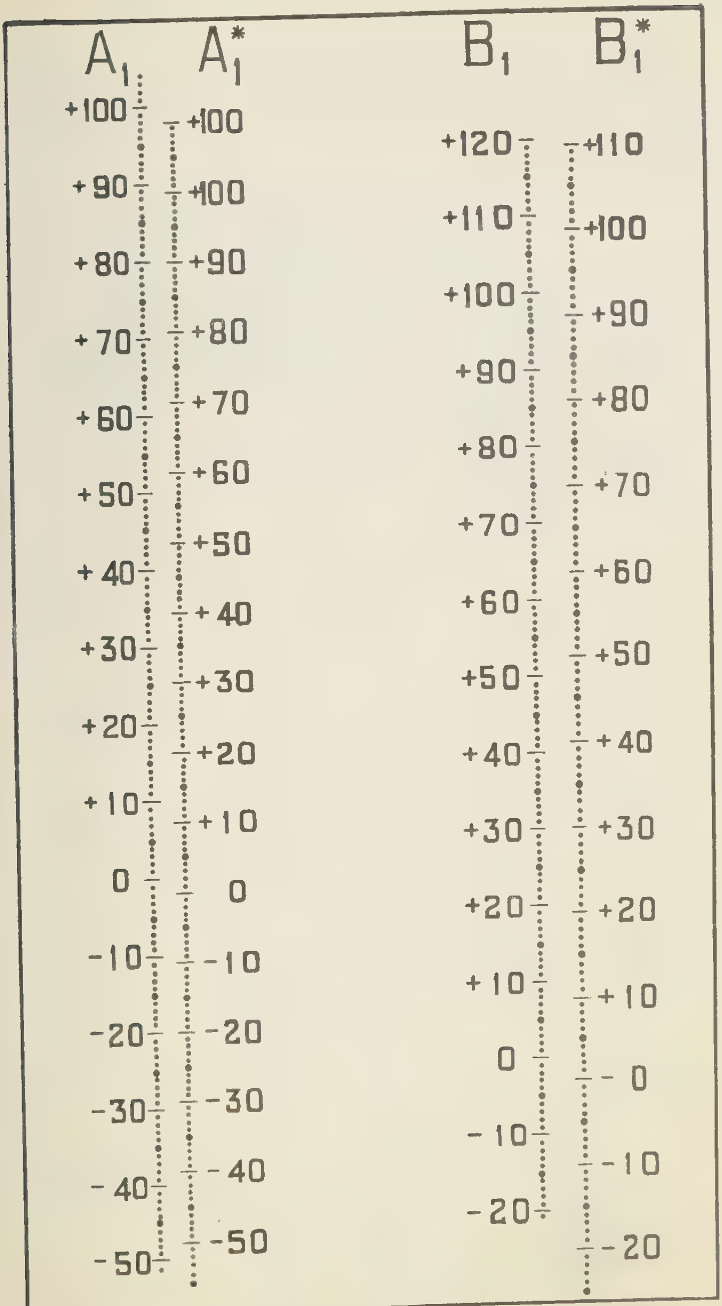

FIG. 2—NOMOGRAPH FOR CONVERSION, IN PHASE AND AMPLITUDE, OF DIURNAL HARMONIC COEFFICIENTS, BATAVIA Y, YEARS AFTER 1920, TO ALLOW FOR CHANGE IN TABULATING SCHEME

will lie at the right hand of (B), since in the present case (2) and (3) yield $u/D > 1$. By combining readings on (A^*) and on (B^*), both values of the transformed Fourier coefficients can be read with a sole position of the intersection line (I,I).

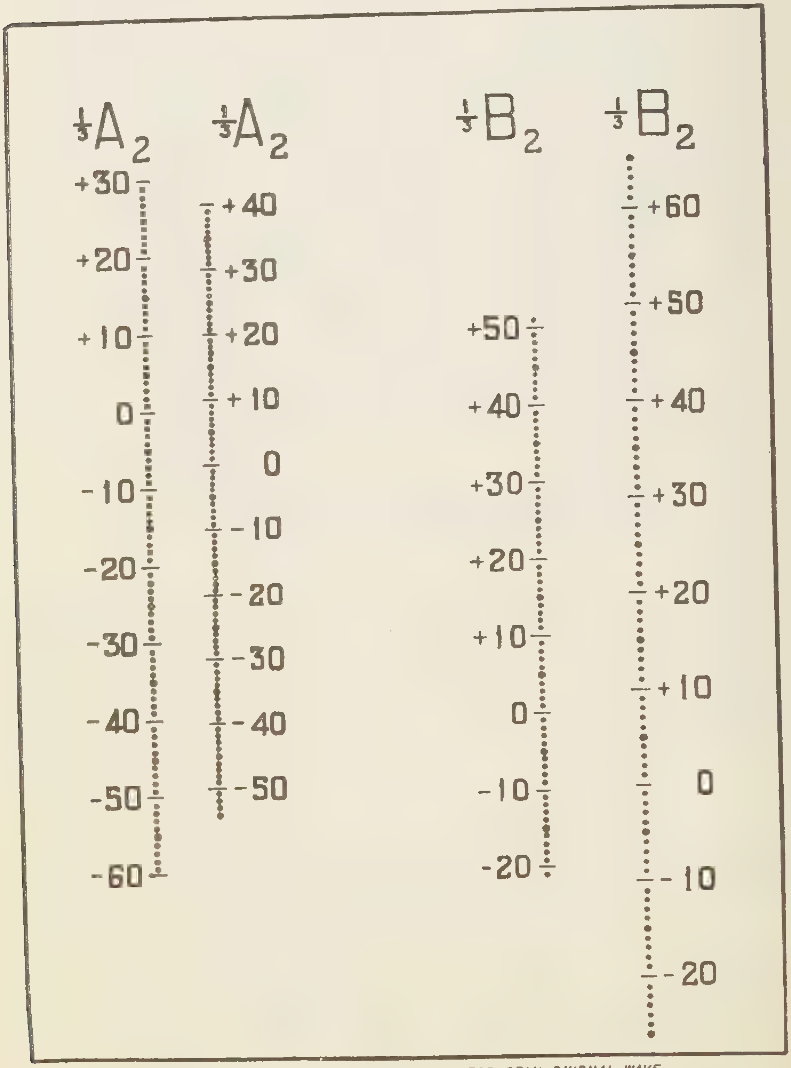

FIG. 3—NOMOGRAPH, AS IN FIGURE 2, FOR SEMI-DIURNAL WAVE

As for the final design of the nomographs, reproduced in Figures 2 and 3, the following details may be given.

(1) Provisional phases and amplitudes may be used throughout, such as are those which correspond to the raw Fourier coefficients obtained by the usual methods of harmonic analysis. Figures 2 and 3, for instance, refer to an analysis made with bi-hourly differences, starting at Greenwich midnight[3]. Reduction of phases to local time, and of amplitudes to cgs units, may be left for a later stage of the work.

(2) According to the most frequent combination of the original values A, B, the position and slope of the zero-line (0,0) should be chosen so as to make the rule (I,I) become horizontal, or nearly so, in the greatest possible number of operations, in order to minimize errors of estimate due to oblique intersection of (I,I) with either of the scales.

(3) For the same reason, dotted scales as shown in Figures 2 and 3, seem to be preferable to ordinary straight lines subdivided by short dashes.

(4) It is convenient to distinguish the two pairs of scales by different colors.

Servicio Meteorológico Nacional,
Buenos Aires, República Argentina, January 29, 1947

[3]See Chapman and Bartels, Geomagnetism, vol. II, Chap. 16, §19 (1940).

LETTERS TO EDITOR

(See also pages 174, 216, 232, and 263)

MEAN MONTHLY VALUES OF MAGNETIC ELEMENTS, CHRISTCHURCH, NEW ZEALAND, ALL DAYS OF 1945

Alterations in buildings at Christchurch Observatory, in March, 1946, interfered with publication of the annual magnetic values for 1945 in the last Annual Report of the Department of Scientific and Industrial Research of New Zealand. The values, as indicated in the following Table, are given so that investigators who wish to see them will not have to wait a full year.

Month	Element			
	D	*H*	*Z*	*I*
1945	° ′	γ	γ	° ′
January	+18 58.6	22218	−55202	−68 04.6
February	+18 59.0	22219	−55205	−68 04.6
March	+18 59.9	22210	−55199	−68 04.9
April	+19 00.5	22210	−55211	−68 05.2
May	+19 01.4	22217	−55205	−68 04.7
June	+19 01.8	22219	−55204	−68 04.6
July	+19 02.3	22215	−55214	−68 05.0
August	+19 02.9	22212	−55209	−68 05.0
September	+19 03.0	22213	−55201	−68 04.8
October	+19 03.2	22210	−55213	−68 05.2
November	+19 03.9	22220	−55192	−68 04.3
December	+19 04.3	22214	−55186	−68 04.4
Year, 1945	+19 01.7	22214.7	−55203.4	−68 04.77
Δ from 1944	+6.7	−6.8	−3.4	−0.45

	Y	*X*	*F*	*G*
				cgs
Year, 1945	07243.0	21000.8	59505.5	0.35431
Δ from 1944	+38.9	−20.6	+0.5	−0.00003

Magnetic Survey of New Zealand, H. F. Baird,
Botanic Gardens, Christchurch, New Zealand, August 16, 1946 *Director*

ELECTRIC CURRENT AS A PROBABLE CAUSE OF DAILY MAGNETIC VARIATION

By K. Terada

Summary—This paper was read, as early as 1941, at the meeting of the Physico-Mathematical Society of Japan held at Hiroshima University. The Japanese text of this paper (with English abstract) with some of the details was published in the *Journal of Meteorological Society* [Ser. II, **20**, 353-369 (1942) and **21**, 171-178 (1943)]. The complete paper has not yet been published because of the War.

The paper is restricted to some physical points only and detailed mathematical treatments and the numerical data are omitted.

Introduction

In 1889, A. Schuster [See 5 of "References" at end of paper] showed that the daily magnetic variation on a quiet day could be divided into the magnetic variation of external origin and that of internal origin. But as the observed data were rather few, this problem has remained untouched systematically about 30 years. In 1919, S. Chapman [6] analysed observed data, far more numerous than those used by Schuster, and obtained the result that the magnetic variation of internal origin can be almost perfectly explained as an electromagnetic induction of the external source—which is a probable cause of the magnetic variation of external origin—in a model Earth having the following property: A uniform distribution of electric conductivity throughout a sphere concentric with the Earth, but of radius four per cent less than that of the Earth, the material on the outer four per cent of the layer (about 250 km thick) being non-conductive and the electric conductivity in the inner core being 3.6×10^{-13} cgs. Similar problems were developed mathematically by T. T. Whitehead [7], A. T. Price [9], K. Terada [14, 16], and B. N. Lahili [18], but the general conclusion as to the feature of the electromagnetic induction, did not differ much from that of S. Chapman [6].

It is not known whether the daily magnetic field is because of a system of electric currents in the upper atmosphere; but, for the sake of discussion, we will suppose that it is. The mathematical treatments showed how the induced currents flow in the crust, as described above, but the magnetic data give no indication of the height above the Earth at which the electric current, which will be a probable cause of the magnetic field of external origin, will be situated. McNish [10] has pointed out that highly accurate measurements of the intensity of the magnetic field in the ionosphere might be used to determine the actual height of the probable current-sheet. But at present the level of this current-sheet remains in doubt. From the numerous radio researches it is assumed that this current will be located in the ionosphere, but this assumption was not made from data based

on magnetic observations. The author discussed a method of assuming the height of this current from magnetic data and deduced a similar conclusion to the assumption derived from the radio data by Appleton [15], Chapman, Bartels [4], and others.

Magnetic force due to electric current in a semi-infinite conductor bounded by a plane surface

If we confine ourselves to a region rather small as compared with the Earth's radius, it is regarded that the Earth is bounded by the plane surface and the ionosphere is parallel to this plane. As the highest part of the ionosphere is about several hundred km and the deepest part of the Earth's crust, which contribute to the location of the inner current, will also be of the order of several hundred km, we can apply the above-mentioned approximation to the region of several thousand km as to the horizontal extension admitting an error of several per cent.

Now the rectilinear cartesian coordinates x, y, z are introduced, with origin on the Earth's surface and x-, y-, z-axes toward south, east, and vertically upwards, respectively. The electric current (i_x, i_y) in the crust is parallel to xy-plane and flows in the region from $z = 0$ to $z + b$; i_x is a function of (y, z) and i_y of (x, z). Now the horizontal domain of this current in this calculation is put to be from $-\Delta$ to $+\Delta$, being far greater than b and a, which is the height of the calculated point from the Earth's surface.

Then the horizontal magnetic force due to the current i_x is

$$-H_y = \frac{2}{C}\int_{-\Delta}^{+\Delta}\int_{-b}^{0}\frac{i_x(a-z)}{(a-z)^2+y^2}\,dy\,dz$$

$$-H_z = \frac{2}{C}\int_{-\Delta}^{+\Delta}\int_{-b}^{0}\frac{i_x\cdot y}{(a-z)^2+y^2}\,dy\,dz$$

Now assuming that the current is expressed by

$$i_x = i_{x_0}(1+\lambda y+\mu y^2) \qquad i_y = i_{y_0}(1+\lambda' x+\mu' x^2)$$

$$\Delta \gg a, b \qquad \mu \ll \lambda \qquad \mu' \ll \lambda'$$

and putting

$$I_{x_0} = \int_{-C}^{0} i_{x_0}(z)\,dz \qquad I_{y_0} = \int_{-C}^{0} i_{y_0}(z)\,dz$$

we have

$$-H_y \doteqdot \frac{2\pi}{C} I_{x_0} \qquad H_x \doteqdot \frac{2\pi}{C} I_{y_0}$$

and the vertical magnetic force due to the current i_x is

$$H_z \doteqdot \frac{4}{C}(I_{x_0} - I_{x\Delta})$$

where $I_{x\Delta}$ indicates the total current summed up the current locating in the vertical direction at a point of $x = \Delta$.

Similarly we have the expressions of the magnetic forces due to i_y. Combining we have

$$H_z \doteqdot \frac{2}{\pi}[H_{y(y=\Delta)} - H_{y(y=0)} + H_{x(x=\Delta)} - H_{x(x=0)}]$$

Now we conclude as follows:

We divide the magnetic forces into those of external origin and of internal origin by a harmonic analysis. From H_x, H_y of internal origin we can calculate the total internal current which flows in the crust under the point considered. From the difference of H_x, H_y at a point far distant from that point under consideration, we can calculate H_z for this point.

Similar conclusion will be deduced for the magnetic forces of external origin.

Current-system which corresponds to the quiet-day daily magnetic variation

Using observed data collected from various widely-distributed stations, S. Chapman calculated the magnetic potential V corresponding to the quiet-day daily magnetic variation by the following formulas.

$$V = aP_n^{n-1}(\cos\theta)\left\{\frac{r^n}{a^{n-1}} C_n^{n-1}(e)\sin[(n-1)t + \alpha_n^{n-1}(e)] + \frac{a^{n+2}}{r^{n+1}} C_n^{n-1}(i)\sin[(n-1)t + \alpha_n^{n-1}(i)]\right\}$$

where

$$P_n^{n-1}(\cos\theta) = \epsilon_n^{n-1}\frac{d^{n-1}P_n(\cos\theta)}{d(\cos\theta)^{n-1}}\sin^{n-1}\theta$$

$$\epsilon_n^{n-1} = \left(\frac{2}{(2n-1)!}\right)^{\frac{1}{2}}$$

and

$$P_n(\cos\theta) = \frac{(2n)!}{2^{2n}(n!)^2}\left[2\cos n\theta + 2\frac{1.n}{1.(2n-1)}\cos(n-2)\theta + \cdots\right]$$

C and α are constants, t is the time whose origin corresponds to local noon, the letters e and i correspond to the external and internal system, respec-

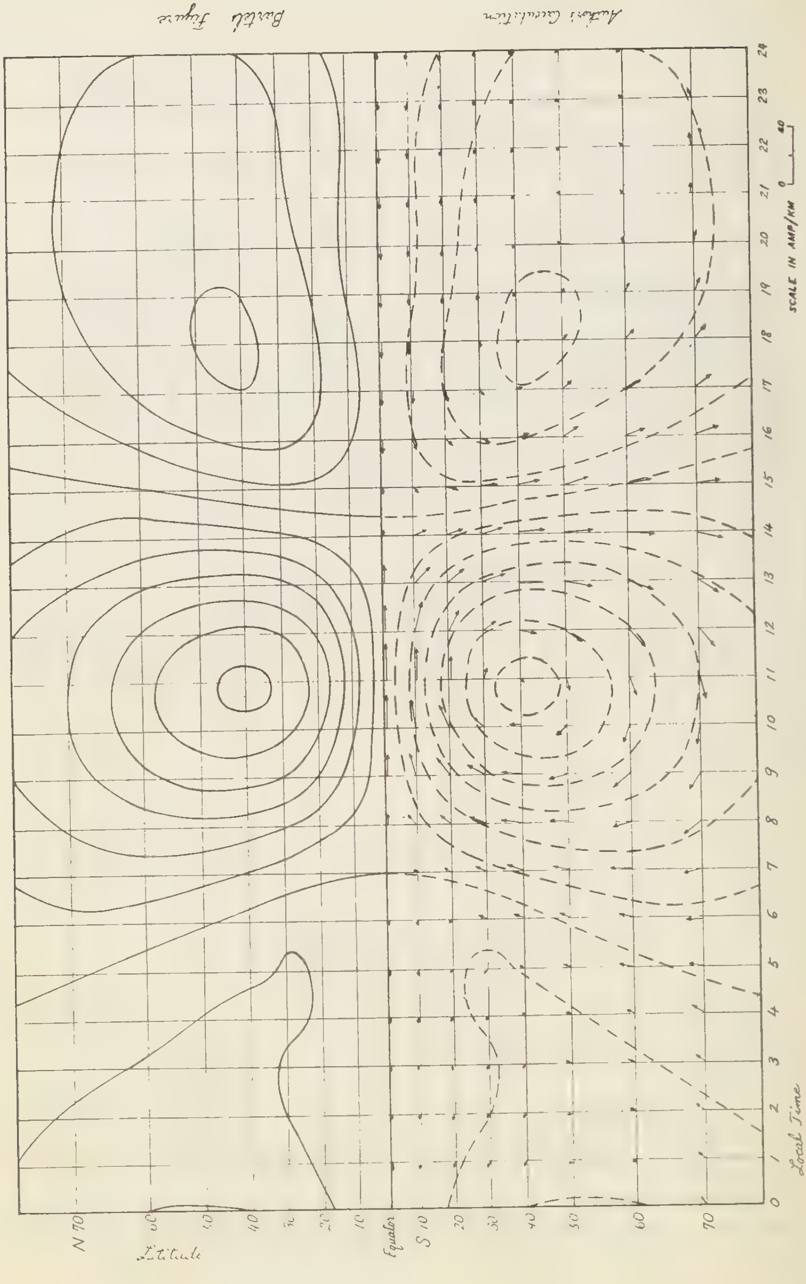

FIG. 1—EXTERNAL CURRENT-SYSTEM

tively. The values of C and α calculated by S. Chapman are as given in Table 1.

TABLE 1—*Values of C and α after Chapman*

n	$C_n^{n-1}(e)$	$\alpha_n^{n-1}(e)$	$C_n^{n-1}(i)$	$\alpha_n^{n-1}(i)$
	Γ	°	Γ	°
2	49.9×10^{-6}	300	16.8×10^{-6}	320
3	29.5×10^{-6}	297	13.2×10^{-6}	315
4	12.0×10^{-6}	312	5.0×10^{-6}	323
5	2.6×10^{-6}	324	0.8×10^{-6}	348

Differentiating the potential we can calculate the three components of the magnetic forces at the Earth's surface. Now we have X_e, Y_e, Z_e and X_i, Y_i, Z_i corresponding to the external and internal origin, respectively. The author calculated these values at every 10° of latitude and every 15° of longitude and assumed them as the observed values of the magnetic forces.

Using the formula given in the preceding section, the general features of the total current which flows in the Earth's atmosphere and in the Earth's crust were calculated and graphed as in Figures 1 and 2. (The upper parts of Figures 1 and 2 are the stream-lines drawn after Bartel's method and the lower parts are those due to the author's method. The author calculated the current-intensity at every intersecting point of longitudinal and latitudinal lines as shown in Figures and the stream-lines at intervals of 10,000 amperes are shown by dotted lines. (In the upper half of Figure 2 the stream-lines at intervals of 5,000 amperes are shown by broken lines.) In these Figures the feature of the current-flow is compared with that obtained by J. Bartels [4], which is deduced mathematically by him from standpoints different than those of the author. As will be seen, the features of the current-flow resemble each other, showing that the mathematical formulas deduced in the preceding section are applicable without large error.

Calculation of the vertical component of the magnetic force

J. Bartels [4] has succeeded in drawing the figure of the horizontal current-system corresponding to the daily magnetic variation. From his figure we can estimate roughly the feature of the variation with time of the vertical force. But the real value of the vertical component should be obtained by the differentiation of the potential-function V and hence it is impossible to calculate the vertical component from the local current in the Earth's atmosphere or the Earth's crust.

But there is a simpler method of treating this problem, namely, assume the current to exist rather near to the Earth's surface as compared with

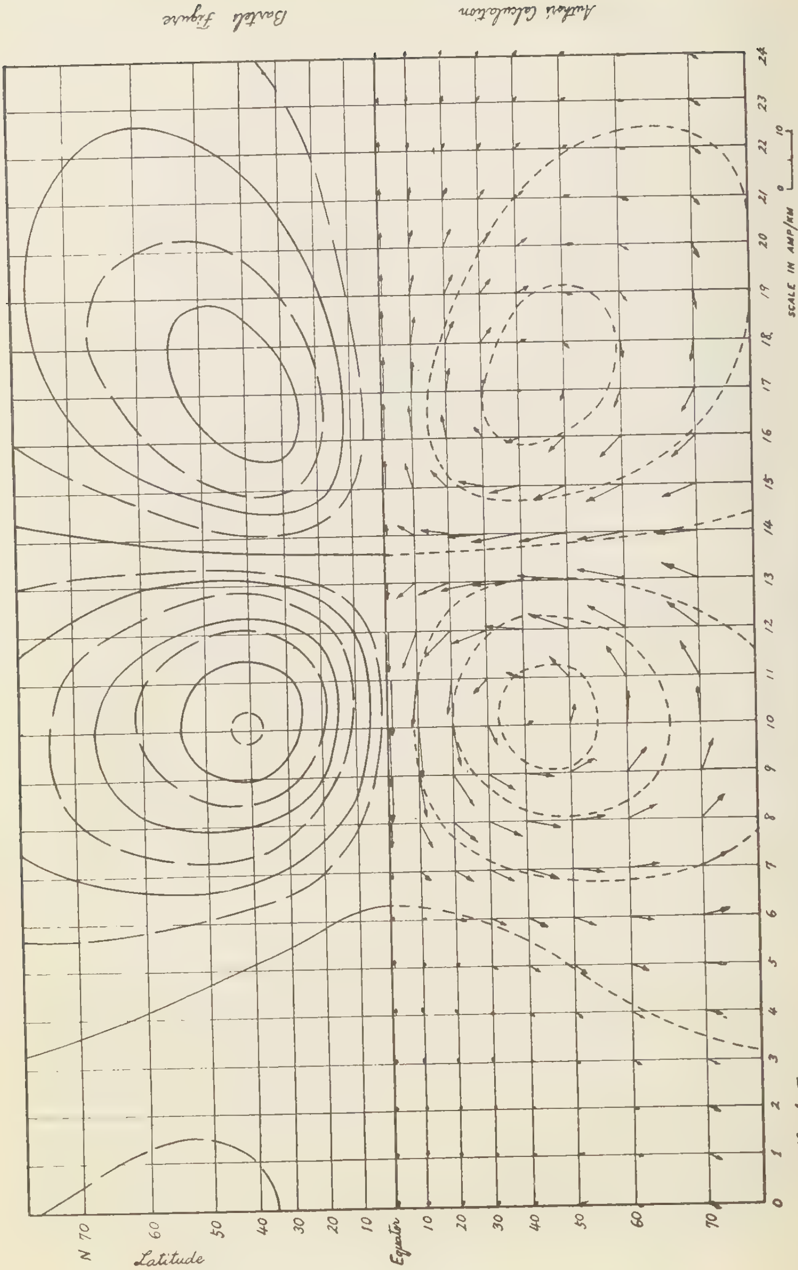

FIG. 2—INTERNAL CURRENT-SYSTEM

the Earth's radius. Then, if we confine ourselves to the region on the Earth's surface, which can be assumed to be a plane, we can treat the above mentioned formulas without serious error. The author treated the region bounded by the longitudinal lines 10° or 20° apart and by the latitudinal lines by 15° or 30° apart. For greater intervals of longitude and latitude the separate regions begin to have some curvature, but as the current lies about several hundred km above or beneath the Earth's surface, the above mentioned treatment may be applied to these regions with errors only of several percentages.

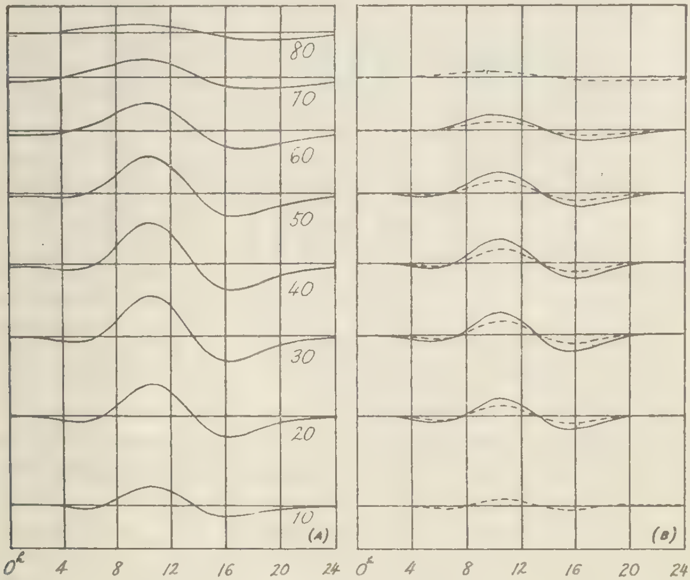

FIG. 3—Z OF INTERNAL PART; (A) = OBSERVED VALUES, (B) = AUTHOR'S CALCULATED VALUES

VERTICAL SCALE IN GAMMAS 0 4 8 12

The author thus calculated the vertical components from the observed values of the magnetic forces only and obtained the results graphed in Figures 3 and 4. (The right-hand curves of Figures 3 and 4 are the curves calculated by the author's method based on the horizontal quadrangles of 20° in longitude and 30° in latitude; the results from horizontal quadrangles of about half of the above case are also graphed in dotted lines and show, as is generally expected, amplitudes far smaller that those for the larger quadrangles. The left-hand curves are the calculated values of the vertical component obtained purely mathematically.) It is seen that the two curves closely resemble each other.

Now we will consider the ratio Z_{cal}/Z_{obs}. This ratio should indicate to

what extent the author's method is applicable. The calculated values are tabulated in Table 2.

TABLE 2—*Values of the ratio* Z_{cal}/Z_{obs}

Local time	External part					Internal part				
	Latitude in degrees					Latitude in degrees				
	60	50	40	30	20	60	50	40	30	20
h										
08	0.74	0.59	0.44	0.26	0.16	0.43	0.19	−0.11	−1.18	−10.00
09	0.75	0.65	0.63	0.55	0.63	0.50	0.33	0.38	0.34	0.29
10	0.76	0.73	0.73	0.72	0.71	0.53	0.51	0.50	0.50	0.49
11	0.75	0.77	0.74	0.74	0.74	0.54	0.54	0.55	0.54	0.54
12	0.75	0.74	0.74	0.73	0.71	0.54	0.55	0.55	0.56	0.59
13	0.75	0.72	0.70	0.68	0.67	0.54	0.55	0.54	0.54	0.54
14	0.75	0.58	0.38	−0.20	−0.33	0.52	0.48	0.45	0.35	0.41
15	0.86	1.12	0.97	0.96	0.94	0.77	0.80	0.79	0.77	0.75
16	0.81	0.84	0.85	0.84	0.83	0.59	0.61	0.63	0.64	0.63
Mean	0.75					0.55				

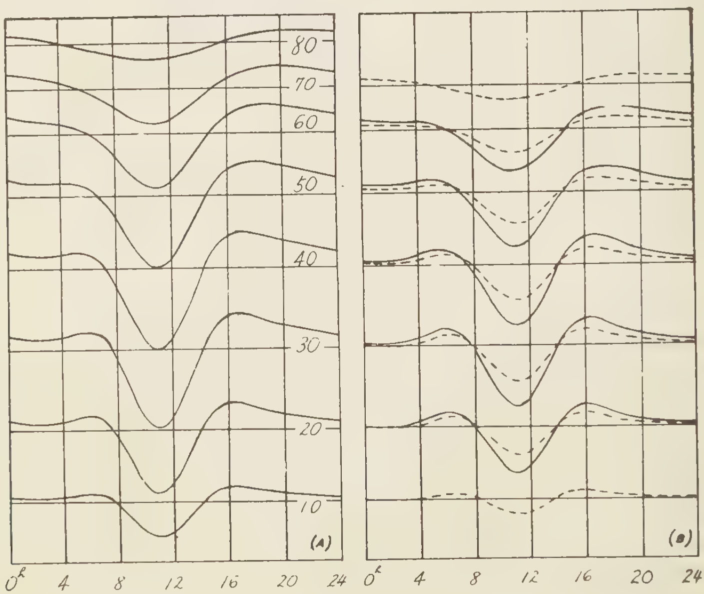

FIG. 4—Z OF EXTERNAL PART; (A)= OBSERVED VALUES, (B)=AUTHOR'S CALCULATED VALUES

VERTICAL SCALE IN GAMMAS

From the values of the ratios in Table 2 and the graphs in Figures 3 and 4 we can deduce the following criteria:

The above-mentioned hypothesis that the current exists very near to the Earth's surface as compared with the horizontal extension of the region now considered, is correct to the first approximation.

The numerical data given in Table 2 show that the calculated values of Z of the external part has a larger contribution than those of the internal part, suggesting that the external current may lie nearer to the Earth's surface than the internal current. The average values of ratios are 75 per cent for external part and 55 per cent for internal part.

From another standpoint we have a knowledge of the situation of the internal current only. Thus, considering this point, we will be able to suggest the situation of the external current which *has never been treated* by the investigation of the magnetic data.

Some ambiguities of this theory and conclusion must be considered because the situation of the inner current is rather ambiguous. We will discuss this on the assumption that the conclusion as to the internal current is roughly correct.

S. Chapman [8] has analyzed the mode of the internal current and recently Lahili and Price [18] have treated this problem under a different hypothesis of the electromagnetic nature of the crust. At any rate, it will be assumed that the general part of the internal current, which contributes to the magnetic field on the Earth's surface, will flow below a depth about 600 to 800 km.

Then the assumption made in the preceding section must be somewhat corrected for the internal part. Thus in this case the assumption that b is far smaller than Δ should be modified a little. Then a simple mathematical treatment* shows that, if we assume that the internal current flows mainly at about 100 km from the Earth's surface, the above calculated ratio of 55 per cent may be modified to about 70 per cent or so. Then comparing with the observed value of 75 per cent for the external part, we deduce that the external current will flow about 100 km or so above the Earth's surface.

Comparison with the data by radio exploration

The above conclusion that the electric current causing the quiet-da daily variation will generally flow in or near the E-layer, has an intimat relation to the result obtained from the wireless researches. First, we consider the Dellinger effect, namely, radio fade-out. This phenomenon occurs suddenly and results in weakening the signal-strength of the radio wave received for about 15 minutes or so, and is generally accompanied by a

*If the vertical forces on the Earth's surface are Z and Z' due to the current flowing in the depth b and b', respectively, we have $Z'/Z = [1 - (C')/\Delta) \tan^{-1} (\Delta/C')]/[1 - (C/\Delta) \tan^{-1} (\Delta/C)]$ in the first approximation.

chromospheric eruption on the Sun's surface and a small disturbance of the Earth's magnetism. The wireless researches indicate that this phenomenon seems to bear an intimate relation to the bottom part of E-layer, but to play a role, to some extent, to E- and $F1$-layers also. On the other hand it is observed that $F2$-layer does not contribute to this effect.

Observations of the geomagnetism during the radio fade-out show the existence of the augmentation of the amplitude of the curve of daily variation. This point was discussed by Imamiti and McNish [13]. Concerning this matter S. Chapman and J. Bartels [4] state: "Simultaneity in the production of this layer and the observation of visible solar flare, show that the ionizing agent travels with speed of light and is, therefore, presumably ultra-violet radiation. In this respect it is similar to the ionizing agents mainly responsible for the E- and $F1$-layers, as has been shown by the study of the decrease of ionization in these layers during solar eclipses. The sudden ionization below the E-layer produces magnetic effect, as Fleming suggested, consisting of an augmentation of the S-field over the sunlit hemisphere, including any peculiarities in the S-field that may exist on the day concerned."

"If the regions which are the location of the ordinary S-field current become suddenly ionized, new and similar currents are set up in them which augment the regular S-field. Taking the location of these extraordinary S-currents to be known, as below the E-layer, a presumption is created that the ordinary S-currents flow in an adjacent regularly ionized layer, and therefore, in the nearest such layer, namely the E-layer, and possibly also in the $F1$-layer."

As the electric current, which may augment the amplitude of the curve of the daily variation, will flow at the bottom of E-layer, it seems apparent that the current, which is a probable cause of the daily variation, may flow near it, namely, in E- or $F1$-layer.

As early as 1937, Appleton [1-5] pointed out that: "As has been suggested by the absorption experiments we consider Region E (and possibly, to some extent, Region $F1$) as the location of the currents causing the magnetic variations. Additional evidence in this connection is the fact that the ionization in Regions E and $F1$ varies by about 50 per cent over the sunspot-cycle, as does the amplitude of the magnetic variation. The variation of Region-$F2$ ionization, on the other hand, exhibits no parallelism with this amplitude, either in respect of seasonal or sunspot-cycle changes, indicating that the magnetic currents do not flow at high levels. In south-east England the maximum ionization in Region $F2$ has been found to be greater in December than in June. Also the variation over the sunspot-cycle is very much greater than 50 per cent."

Summarizing the above discussions we arrive at the plausible conclusion that the electric current, which is a probable cause of daily magnetic

variation, flows in the *E*- or *F*1-layer—a conclusion based not only on radio data but also on magnetic data, although the latter include some ambiguities.

Conclusion

Simple formulas have been deduced which may be used to calculate the electric currents of external and internal origin causing the daily magnetic variation. These current-systems are found to agree with those obtained in a purely mathematical treatment by J. Bartels [4]. It is shown this simple method may be applied without serious errors.

The author's calculations (to the first approximation) of the vertical component of the daily magnetic variation, as compared with observed values, indicate the location of the external current, with some ambiguities depending upon the characteristics of the electric currents in the interior of the Earth's crust. The results appear to be the first to show the location of the electric current of external origin of the daily magnetic variation from study of observed geomagnetic data.

The plausible conclusion is that the electric current probably responsible for the daily magnetic variation flows in the *E*-layer or its neighbor. This may be a valuable contribution in the reconstruction of the physical theory on the cause of the daily magnetic variation and also in further supporting physical investigations of the ionosphere itself.

In concluding this paper the author expresses his cordial thanks to Professor S. Fujiwhara, Director of the Central Meteorological Observatory, to Dr. H. Hatakeyana and Professor M. Hasegawa for encouragment and advice, and to Mr. G. Potter for his aid in having the manuscript forwarded for publication.

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Tokyo, Japan, August, 1946

DIURNAL VARIATIONS OF COMPUTED ELECTRIC CURRENTS IN THE HIGH ATMOSPHERE

By E. Sucksdorff

This investigation is based on the supposition that the observed departures of the geomagnetic force from a mean value are caused by infinite electric line-currents, or at least very narrow ones, which flow across the meridian. It has been done according to a simple trigonometric method.

The departures of the components of the magnetic force in a vertical geographic meridian plane through the station are expressed by ΔX and ΔZ. The ratio $(\Delta X/\Delta Z) = \tan \alpha$, in which α stands for the angle between the resultant vector and the downward direction, which is the same as the elevation-angle of the supposed line-current in the meridian plane above the horizon. Thus the direction towards the current is determined. From the positive or negative sign of ΔX and ΔZ it can be concluded whether the current flows to the north or south of the station and whether its direction is eastward or westward.

When two recording stations are available on (or near) the same meridian and the direction towards the line-current is determined in this way from both the stations, the location in space of the current will be defined. Likewise the intensity of the current can be calculated from either of the stations on the basis of the size of the resultant vector and the distance of the current. In the Polar Year of 1932-33 there were three such couples of observatories in operation at which both stations were so close to the same meridian that their recorded results could be used in this investigation with sufficient accuracy. These stations are listed in Table 1, together with their geographic (φ, λ) and geomagnetic (Φ, Λ) coordinates;—the last column (τ) shows the local mean geomagnetic time at Greenwich noon.

Table 1—*Three couples of observatories with their coordinates, Polar Year 1932-33*

Station	φ	λ	Φ	Λ	Ψ	τ
	°	°	°	°	°	h
Meanook	54.6	246.7	61.8	301.0	17.2	03.5
Fort Rae	62.8	243.9	69.0	290.9	24.1	02.8
Sodankylä	67.4	26.6	63.8	120.0	−26.7	15.4
Petsamo	69.5	31.2	64.9	125.8	−27.6	15.8
Godhavn	69.2	306.5	79.8	32.5	−17.5	09.6
Thule	76.5	291.1	88.0	359.3	− 0.6	07.4

These three "observatory couples" are geographically very favorably situated from the point of view of this investigation. Two of them are immediately beyond the northern auroral zone, lying on its opposite flanks, and the third inside the zone, near the geomagnetic axis-pole. Thus all the stations, with the exception of Godhavn, are approximately on the same geomagnetic meridian, its longitude being $\sim 120°$ (300°).

The purpose of this investigation was to determine the average variations in the course of the day of the supposed atmospheric electric currents of the polar cap. As values of ΔX and ΔZ have thus been used the mean hourly departures taken (or computed) from the tables of the diurnal inequalities published in the Year-Books of the Observatories concerned. These values ΔX and ΔZ have been used as such, without subtracting the corresponding values for quiet days from them, because the regular diurnal variation might also be assumed to originate in electric currents. The currents have been computed for all days and separately for international disturbed and for quiet days in each season, but the results presented here refer to the whole Polar Year 1932-33.

Table 2—*Diurnal variations of electric currents computed on the basis of the magnetic diurnal inequalities from Meanook and Fort Rae for the Polar Year 1932-33* (*local time*)

Local time	All days					Disturbed days					Quiet days				
	φ	Φ	h	I	d	φ	Φ	h	I	d	φ	Φ	h	I	d
h	°	°				°	°				°	°			
01	60.2	67.2	469	134	W	55.8	62.9	166	81	W	....	....	....	...	..
02	59.0	66 0	394	126	W	56.6	63.7	405	241	W	....	....	....	...	..
03	59.4	66.4	363	125	W	58.0	65.0	356	264	W	....	....	....	...	..
04	59.1	66.1	371	114	W	57.7	64.8	388	316	W	....	....	....	...	..
05	59.3	66.3	408	89	W	57.5	64 6	470	323	W	....	....	....	...	..
06	60.4	67.3	467	85	W	58 6	65 6	602	319	W	....	....	....	...	.
07	61.6	68.4	490	56	W	59.4	66.4	670	220	W	....	....	....	...	..
08	62.7	69.5	1060	59	W	59.9	66.9	726	178	W	....	....	....	...	W
09	....	....	....	...	W	62.4	69.3	432	35	W	....	....	....	...	W
10			.		W										W
11					W		.					.			W
12	....	....	....	. .	.	57.9	65.0	714	186	E	....	....	....	. .	W
13	61 9	68.8	399	50	E	60 1	67.1	1138	390	E	....	....	....	...	..
14	62.3	69.2	754	105	E	60 8	67.8	1220	497	E	....	....	....		
15	62 6	69.4	984	165	E	60.7	67.6	1153	535	E	64.6	71.4	722	31	E
16	62.4	69.3	1028	196	E	60.7	67.6	944	469	E	72.7	79.1	4647	209	E
17	61.8	68.6	862	189	E	60 4	67.3	784	409	E	76.6	82.9	7960	499	E
18	61.5	68.4	746	188	E	60.1	67.1	684	386	E	69.9	76.4	3222	204	E
19	61.1	68.0	602	148	E	59 6	66.6	500	282	E	69 4	76 0	4072	197	E
20	60 3	67.2	528	118	E	58.7	65.7	348	193	E	64.6	71.4	1928	74	E
21	59.5	66.5	465	87	E	59 0	66.0	324	149	E	61.5	68.4	688	27	E
22	57.4	64.5	358	34	E	56 0	63.1	246	35	E	58.2	65.2	923	23	E
23	54 0	61.2	200	3	E	....	....	....	...	W	55 1	62.3	593	12	E
24	....	....	....	...	W	....	....	....	...	..	....	..			
Means	60.3	67.3	576	109	..	59.0	66.0	614	275	..	....	....	....		
W	60.2	67.2	503	98	W	58 4	65.5	468	220	W	....	....	....	...	..
E	60.4	67.4	630	117	E	59 5	66.4	732	321	E	65 8	72.6	2751	142	E

The results obtained are evidently to some extent affected by the influence of induced earth-currents on the geomagnetic departures recorded by the Observatories. At present an estimation of this influence is, however, very uncertain, and it would have to be based on mere assumptions. In

TABLE 3—*Diurnal variations of electric currents computed on the basis of the magnetic diurnal inequalities from Sodankylä and Petsamo for the Polar Year 1932-33 (local time)*

Local time	All days					Disturbed days					Quiet days				
	φ	Φ	h	I	d	φ	Φ	h	I	d	φ	Φ	h	I	d
h	°	°				°	°				°	°			
00.5	70.7	66.8	406	174	W	69.3	65.5	454	462	W	....	....	....	...	..
01.5	71.2	67.2	412	180	W	70.2	66.3	474	480	W	....	....	....	...	..
02.5	71.6	67.6	436	153	W	71.0	67.0	446	299	W	71.2	67.2	158	32	W
03.5	72.3	68.2	460	123	W	72.5	68.4	578	285	W	....	....	....	...	..
04.5	....	....	....	...	W	(81.9)	(76.8)	(1884)	(659)	W	64.8	61.4	416	9	E
05.5	....	....	....	...	E	....	....	....	...	W	67.0	63.4	1108	22	E
06.5	....	....	....	...	E	....	....	....	...	E	....	....	....	...	E
07.5	(66.5)	(63.0)	(1786)	(36)	E	(66.3)	(62.8)	(1222)	(53)	E	....	....	....	...	E
08.5	(69.9)	(66.0)	(76)	(6)	E	70.0	66.1	216	29	E	66.3	62.8	1061	19	W
09.5	....	....	....	...	..	70.5	66.6	146	45	E	....	....	....	...	W
10.5	....	....	....	...	..	70.5	66.6	134	56	E	66.8	63.2	1625	121	W
11.5	....	....	....	...	..	70.6	66.7	174	80	E	67.1	63.5	958	80	W
12.5	....	....	....	...		71.1	67.1	260	128	E	67.1	63.5	692	48	W
13.5	70.4	66.5	106	39	E	71.4	67.4	364	199	E	66.8	63.2	270	12	W
14.5	71.6	67.6	300	85	E	71.2	67.2	446	293	E	....	....	....	...	..
15.5	71.8	67.7	478	139	E	70.6	66.7	564	393	E	71.6	67.5	150	14	E
16.5	71.7	67.6	576	178	E	70.2	66.3	569	420	E	82.0	76.8	1544	79	E
17.5	71.4	67.4	616	195	E	69.3	65.5	502	385	E	....	....	....	...	E
18.5	70.9	66.9	626	169	E	68.7	65.0	422	245	E	....	....	....	...	E
19.5	71.2	67.2	703	147	E	68.7	65.0	460	165	E	....	....	....	...	E
20.5	70.6	66.7	614	86	E	67.9	64.2	188	30	E	....	....	....	...	E
21.5	....	....	....	...	..	70.5	66.6	428	113	W	....	....	....	...	E
22.5	70.5	66.6	382	74	W	68.8	65.1	600	303	W	67.1	63.5	230	8	E
23.5	70.7	66.8	354	124	W	69.7	65.9	490	397	W	....	....	....	...	..
Means	71.2	67.2	462	133	..	70.1	66.3	396	240	..	68.9	65.1	747	40	..
W	71.2	67.2	408	138	W	70.3	66.4	496	334	W	67.6	63.9	794	52	W
E	71.2	67.2	502	130	E	70.1	66.2	342	190	E	70.5	66.5	690	26	E

TABLE 4—*Diurnal variations of electric currents computed on the basis of the magnetic diurnal inequalities from Godhavn and Thule for the Polar Year 1932-33 (local time)*

Local time	All days					Disturbed days					Quiet days				
	φ	Φ	h	I	d	φ	Φ	h	I	d	φ	Φ	h	I	d
h	°	°				°	°				°	°			
01	78.4	89.4	802	333	E	78.2	89.2	890	637	E	77.4	88.4	602	144	E
02	78.2	89.2	775	339	E	78.5	89.6	1026	724	E	77.4	88.4	520	131	E
03	78.1	89.1	698	345	E	78.2	89.2	949	707	E	77.2	88.1	388	136	E
04	77.7	88.7	592	335	E	78.1	89.1	831	684	E	76.9	87.9	259	144	E
05	77.5	88.5	462	293	E	77.9	88.9	768	538	E	76.6	87.5	318	135	E
06	77.2	88.2	358	247	E	78.2	89.2	812	469	E	....	....	....	...	
07	76.8	87.8	220	172	E	78.6	89.6	1030	385	E					
08	....	....	....	...	..	(85.1)	....	(5790)	(593)	E	....	....	....	...	..
09	....	....	....	...	..	....	....	....	...	E	70.7	81.4	425	35	W
10	76.8	87.8	227	140	W	76.6	87.6	168	251	W	76.9	87.9	524	81	W
11	76.7	87.7	133	235	W	76.8	87.8	160	409	W	....	....	....	...	..
12	76.8	87.8	222	338	W	77.4	88.4	566	653	W	....	....	....	...	..
13	76.9	87.9	260	373	W	77.5	88.5	619	759	W	....	....	....	...	..
14	77.2	88.2	352	368	W	77.6	88.7	776	794	W	....	....	....	...	..
15	77.5	88.5	456	335	W	78.4	89.4	927	783	W	....	....	....	...	..
16	78.0	89.1	633	319	W	78.9	90.0	1162	718	W	76.8	87.8	118	121	W
17	78.7	89.8	896	311	W	78.9	90.0	1008	493	W	77.9	88.9	457	121	W
18	(80.9)	....	(2075)	(421)	W	(83.1)	....	(36 0)	(992)	W	78.4	89.4	916	148	W
19	....	....	....	...	W	....	....	....	...	W	(83.1)	....	(3130)	(234)	W
20	....	....	....	...	W	....	....	....	...	W	....	....	....	...	W
21	76.5	87.4	55	89	E	76.7	87.7	126	154	E	....	....	....	...	W
22	77.5	88.4	378	184	E	77.4	88.4	762	274	E	76.9	87.9	294	90	E
23	77.7	88.7	468	238	E	77.4	88.4	676	377	E	77.7	88.7	588	128	E
24	78.3	89.3	678	303	E	77.7	88.7	704	497	E	77.7	88.7	631	136	E
Means	77.5	88.5	456	279	..	77.8	88.9	735	542		76.8	87.8	465	119	
W	77.3	88.4	397	302	W	77.8	88.8	673	608	W	76.1	87.1	488	101	W
E	77.6	88.6	499	262	E	77.9	88.9	779	495	E	77.2	88.2	450	130	E

this study the effect of the internal part of the disturbance field has thus been entirely neglected. For that reason the figures given here cannot be

considered exact in themselves; especially the figures for the height and intensity should therefore be regarded as somewhat overestimated.

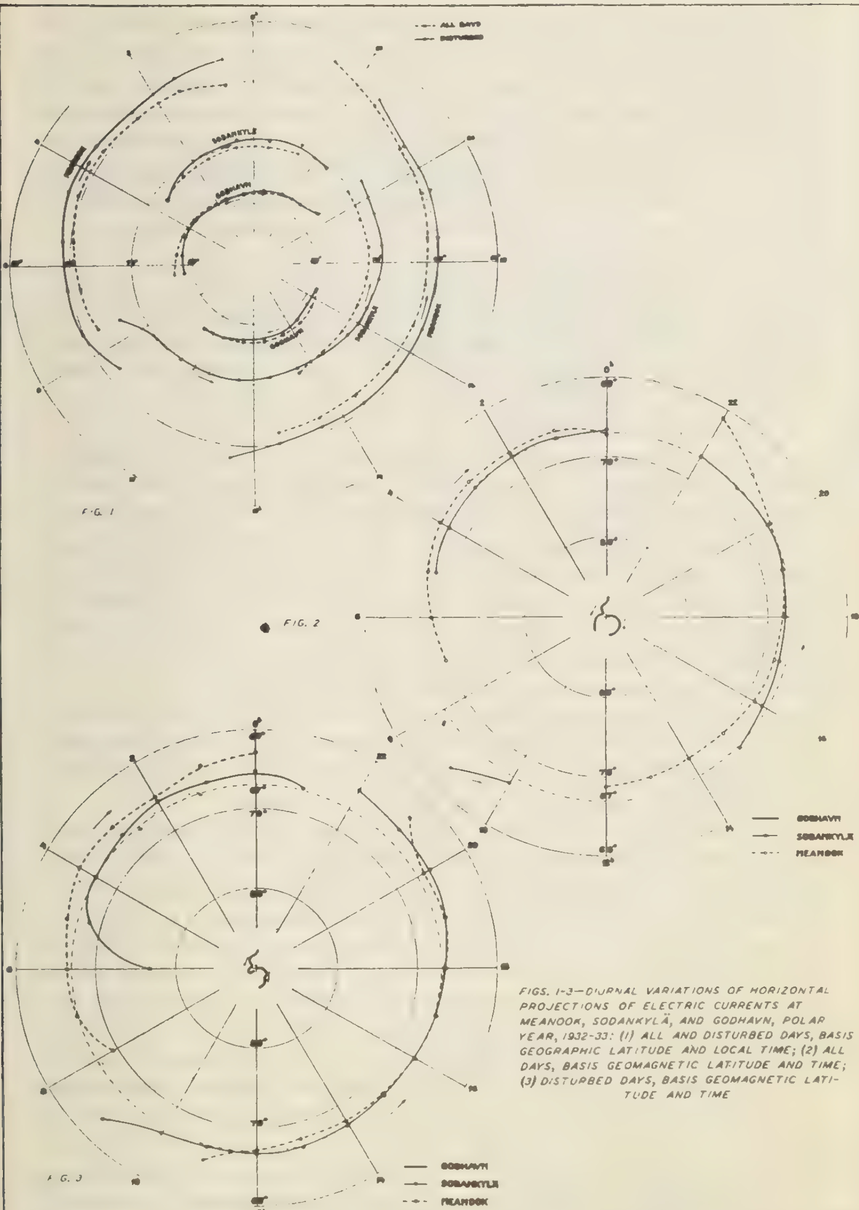
The average results of the computation comprising the Polar Year are entered in Tables 2 to 4, and they are illustrated by diagrams. The first column of the Tables gives the local hour, the second, and third the latitude of the horizontal projection of the current on the geographic (φ) and geomagnetic (Φ) meridians of the Observatory, the fourth column (h) the height of the current from the surface in kilometers, the fifth (I) its intensity in thousands of amperes, and the sixth (d) the direction of the positive current, all computed for "all" days; in the following columns are the corresponding values for international disturbed and quiet days. When computing the means the figures in parentheses (being in some respect uncertain) have not been included.

As seen from the Tables and Figures, results were not obtained for every hourly interval of the day; there are considerable gaps. These are caused in most cases by the directions towards the current given by the two Observatories diverging in these hours, that is, they give negative values for the height. Such cases are most common on quiet days. When an eastern or western current begins or ceases it is also often observed that one of the Observatories of the couple indicates a current opposite to that indicated by the other station, the station situated farther north generally recording the new beginning current one or two hours earlier than that lying farther south; this also causes gaps in the results. It can be observed in general that the disturbed days are the most complete and regular, in contrast to the quiet days. The results of Godhavn-Thule are more regular than those obtained from the stations outside the auroral zone.

As regards the Figures it should be observed that they all, including the maps in Figures 1 to 3 and 8 to 10, present the variations of the current-flows (Fig. 7, the variations of magnetic activity) in the course of the day in three couples of Observatories on the polar cap. With a certain reservation, Figures 8 to 10 also show the actual geographical map of the currents, bearing especially in mind, however, that the two branches of the currents nearest to the axis-pole do not appear simultaneously—one appears in the forenoon, the other in the afternoon. In the Figures, and generally also in the text, only the name of the southern station is used in reference to the couples. In all Figures, except in the first, the local mean geomagnetic time has been used, according to which the time of appearance of the currents at the different stations coincide still better than by the use of local solar time. The arrows in the diagrams denote the directions of the positive current.

The most important results are briefly as follows:

(a) The course of the currents determined by this simple method is



FIGS. 1-3—DIURNAL VARIATIONS OF HORIZONTAL PROJECTIONS OF ELECTRIC CURRENTS AT MEANOOK, SODANKYLÄ, AND GODHAVN, POLAR YEAR, 1932-33: (1) ALL AND DISTURBED DAYS, BASIS GEOGRAPHIC LATITUDE AND LOCAL TIME; (2) ALL DAYS, BASIS GEOMAGNETIC LATITUDE AND TIME; (3) DISTURBED DAYS, BASIS GEOMAGNETIC LATITUDE AND TIME

surprisingly regular, and especially regular on the disturbed days. This impression of regularity is still increased by the diurnal variations of the currents being, in all essentials, similar when studied separately during each season. It is evident that the electric process, which according to our assumption in the end causes the magnetic disturbance around the polar cap, is a rather regular phenomenon itself. From this result the impression is also gained that the presumed ribbon-like shape of the currents on which the work is based, could really, at least in many essential respects, give a credible picture of the real circumstances.

(*b*) There are two (at least apparently) isolated systems of currents. Others flow along the auroral zone more or less horizontally, others in the immediate neighborhood of the geomagnetic-axis pole, resembling vertical currents. The result obtained seems to show that there were no other concentrated currents in the area between these two systems.

Currents along the auroral zone—

(*c*) The currents along the auroral zone have two branches which are separated from each other by a gap or a clear discontinuity. The result is in this respect in excellent agreement with that obtained recently by Harang by another method [Terr. Mag., **51**, p. 353]. We call these branches the forenoon current which flows towards the west and afternoon current, flowing towards the east, although the currents are not strictly limited to these parts of the day. According to the results from Sodankylä, as well as those from Godhavn, the first-mentioned is chiefly a night current, according to the results from Meanook a forenoon current.

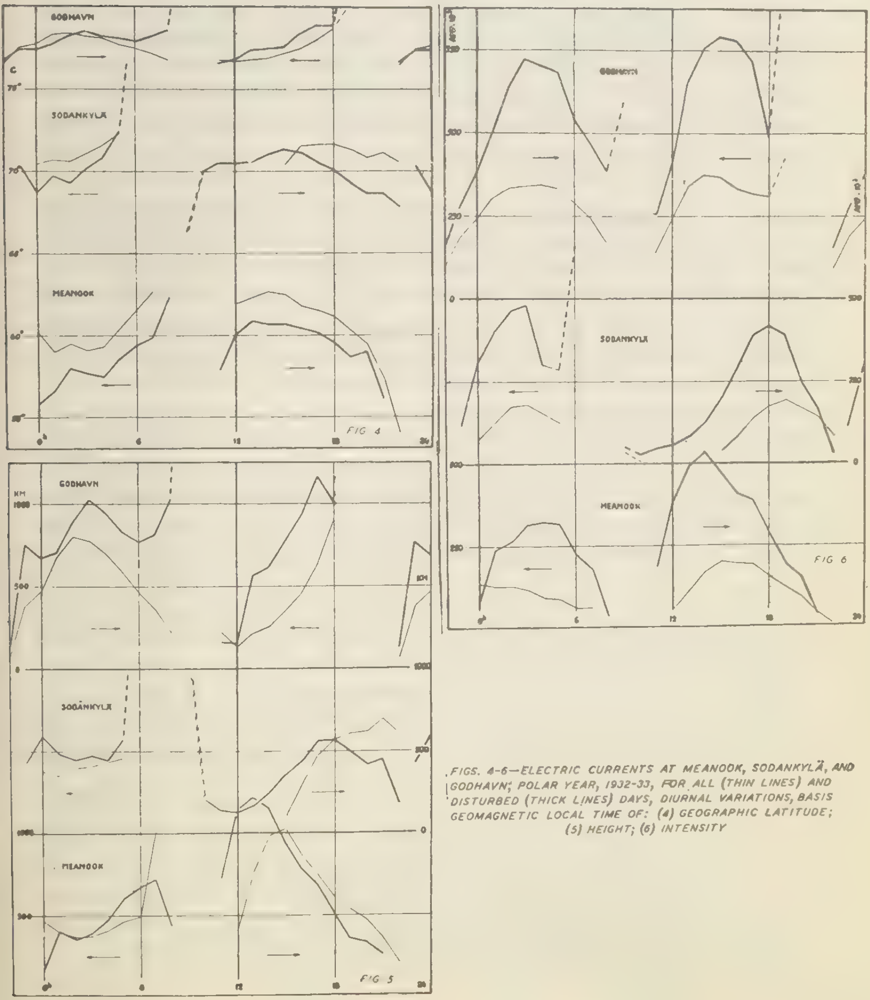
(*d*) The results from both Sodankylä and Meanook show that the currents of both the branches flow on an average (practically) in the same geomagnetic latitude. The auroral zone is thus, at least on the geomagnetic meridian 120°, symmetric with regard to the axis-pole.

(*e*) The increase of the geomagnetic activity causes a strengthening of both branches and a considerable expansion of the current-zone outward (the currents of the quiet days cannot here be taken into consideration). It should be mentioned in this connection (although the corresponding values are not published here) that the currents appear in winter farthest in the north and at the equinoxes farthest in the south, thus corresponding also in this respect to the mean changes of geomagnetic activity. The expansion applies both to the whole forenoon and to the whole afternoon branch (Fig. 1). In the expansion of this zone the pronounced diurnal variation of the magnetic activity with its maxima at midnight and minima at noon (Fig. 7) is expressed very weakly, if at all, as the expansion is largely similar at all times of the day. From this may be concluded that the action of the current-systems, which produce the magnetic disturbances, is of fairly long duration. In other words, the auroral zone remains generally in a state of expansion during the disturbed time, while the

magnetic-disturbance maximum moves from one meridian to another in the course of the day.

The mean AZ-activity figures from Sodankylä vary during the Polar Year from 142 on all days to 392 on disturbed days, being thus almost trebled, and this increase of activity corresponds to the expansion of the auroral zone by on an average 1° outwards.

(f) The latitude of the horizontal projection of the forenoon W-current



FIGS. 4-6—ELECTRIC CURRENTS AT MEANOOK, SODANKYLÄ, AND GODHAVN; POLAR YEAR, 1932-33, FOR ALL (THIN LINES) AND DISTURBED (THICK LINES) DAYS, DIURNAL VARIATIONS, BASIS GEOMAGNETIC LOCAL TIME OF: (4) GEOGRAPHIC LATITUDE; (5) HEIGHT; (6) INTENSITY

increases continually after midnight, and before this flow ends, at about 6 o'clock magnetic time, the current moves more and more rapidly towards the axis-pole (Fig. 2 to 4). If a connection can be shown to exist between such a change of latitude and the magnetic activity, it is in agreement with the reduced activity observed at Sodankylä in the forenoon (Fig. 7). On the other hand, the afternoon *E*-current follows quite a different course: The latitude of its horizontal projection is smallest at the beginning and the end of the current, and greatest at the middle, about the time of the local noon or a few hours after it. Such a change has no counterpart in the diurnal change of the magnetic activity, but it seems as if it might rather be due to solar influence (compare also Fig. 10-*A*). A solar effect of this kind on the *E*-current will be reverted to later on under (*i*). The horizontal projections of both the current-branches are very nearly the same according to calculations from Sodankylä and from Meanook; in Figures 8 and 9, which are to some extent diagrammatized, they are described by one curve.

(*g*) The mean height of the currents is some 500 km (disregarding the effect of the induced internal currents, as mentioned already). Measured from Meanook it is about 170 km greater than from Sodankylä. On disturbed days the mean altitudes are slightly lower than on all days. The afternoon *E*-current flows on an average about 100 km higher than the forenoon *W*-current. In both current branches great heights appear a few hours before noon, in the beginning of the (positive) currents.

The diurnal variations of the heights measured from Sodankylä and Meanook (Fig. 5) show some discrepancies which will be dealt with more closely under (*i*). The height of the forenoon current, on the whole, increases continually in accordance with the time of the day from Sodankylä as well as from Meanook, but the variations in the height of the afternoon current observed from these stations do not coincide with the same (mag-

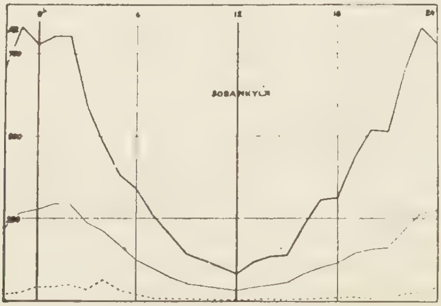


FIG. 7—DIURNAL VARIATION OF GEOMAGNETIC ACTIVITY ON DISTURBED, ALL, AND QUIET DAYS, EXPRESSED BY ΔZ-VALUES AT SODANKYLÄ, POLAR YEAR, 1932-33, BASIS GEOMAGNETIC LOCAL TIME

netic) time. Thus it has not been possible to combine the height-curves of the *E*-branch, similarly as the *W*-curves, in Figures 8 and 9, but separate curves have been drawn for Sodankylä and for Meanook. It may be observed, that these two couples of stations give a similar course for disturbed and all days, but the curves of the latter are some hours late compared with those of the former. A corresponding delay can be noted also in the afternoon curves of the magnetic latitude and the intensity of the current (Fig. 4 and 6).

The result from Meanook indicates the presence of a correlation between the height and the magnetic activity in the course of the day in that the height is inversely proportional to the activity. The results from Sodankylä show such a correlation solely with reference to the forenoon current. It is doubtful, however, whether this correlation can be considered anything but incidental.

(*h*) The average intensity of the currents along the auroral zone is 120,000 amperes, but it increases on disturbed days to more than the double—260,000 amperes on an average. At Sodankylä the *W*-current is generally stronger, at Meanook the *E*-current, but the difference between them is slight and can scarcely be regarded as real. The intensity of the currents is on an average greatest at the equinoxes (124,000 amperes), smallest in the winter (100,000 amperes), similar to the magnetic activity (the corresponding *AZ*-values are 172 and 137).

The intensity of both current-branches changes fairly regularly in such a way that it is greatest in the middle of both branches (Fig. 6). The only exception is the sudden intensification at the end of the *W*-current noted at Sodankylä on disturbed days; with this coincides a maximum intensity of the pole-current. The variations in intensity in the course of the day do not seem to have any connection with the diurnal variation of the magnetic activity [compare (*e*)].

(*i*) In studying the variations in the height and intensity of the afternoon *E*-currents on the basis of the results from Sodankylä and Meanook presented in Figures 5 and 6, attention is drawn to the fact that the maxima of the curves for Sodankylä are some four hours late compared with those of the curves for Meanook. However, these curves coincide better as regards their shape (but not their flowing-times), if the diagrams are drawn for this part according to local solar time. Thus the time of the maxima will be about 17^h or 18^h. The curves of the forenoon current, on the other hand, coincide less well, if the local solar time is substituted for the magnetic time. It is evident in any case that the afternoon *E*-current, being a day current to a greater extent than the *W*-current, is dependent on the Sun's position. Such a dependence is not observed in the (night) *W*-current.

The fact that the curves for height and intensity of the *E*-current, computed on the basis of results from Sodankylä-Petsamo for the winter

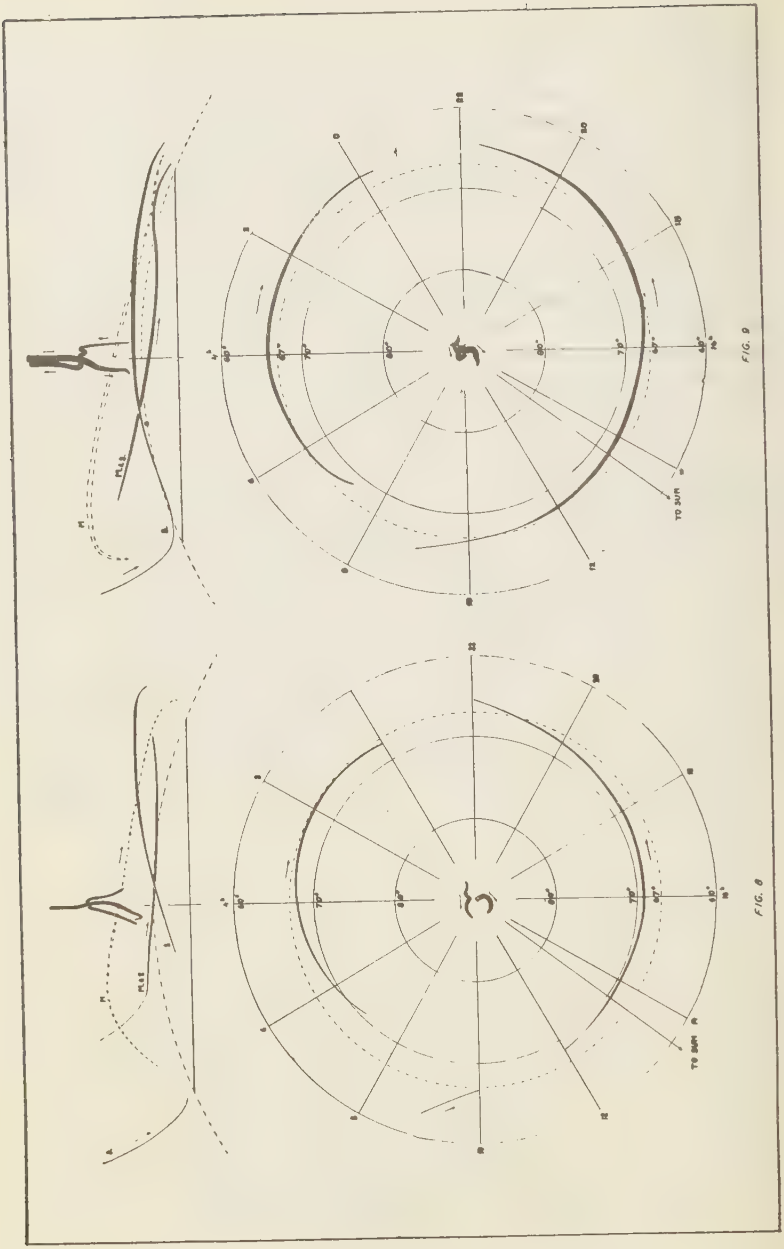


FIG. 9

FIG. 8

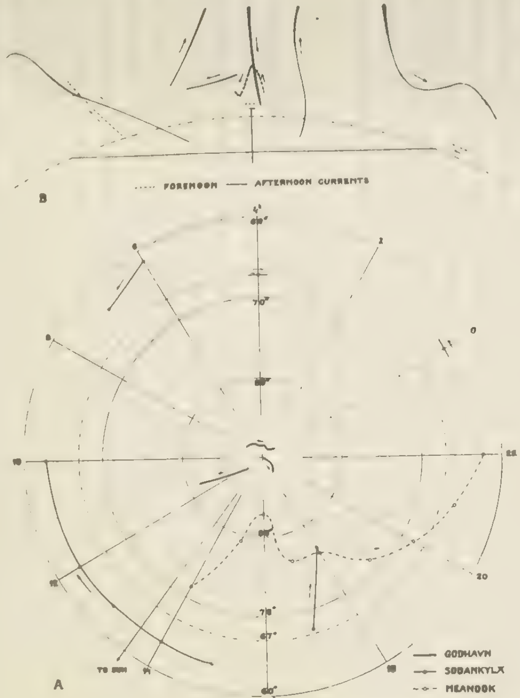


FIG 10

FIGS. 8-10—DIAGRAMMATIC DRAWINGS OF DIURNAL VARIATIONS OF ELECTRIC CURRENTS AT MEANOOK, SODANKYLÄ, AND GODHAVN, POLAR YEAR, 1932-33: (8,9) SEEN FROM ABOVE MAGNETIC-AXIS POLE (LOWER CURVES) AND FROM SIDE FROM DIRECTION OF 16h MERIDIAN (UPPER CURVES), BASIS GEOMAGNETIC LATITUDE AND TIME FOR ALL DAYS AND DISTURBED DAYS; (10) DIURNAL VARIATIONS OF HORIZONTAL PROJECTIONS (LOWER CURVES) OF ELECTRIC CURRENTS ON QUIET DAYS AND (UPPER CURVES) SAME CURRENTS DIAGRAMMATICALLY SEEN FROM SIDE OF POLAR CAP FROM DIRECTION OF 16h MERIDIAN, BASIS GEOMAGNETIC LATITUDE AND TIME [THICKNESS OF CURVES IS PROPORTIONAL TO INTENSITY OF CURRENTS]

months alone, are considerably lower and flatter than those obtained for the summer months only, is also evidence for this dependence on the Sun. This appears also in the corresponding curves from Meanook-Fort Rae, although not in such a pronounced way. It may be easily explained as being due to the location of the latter two stations in a geographic latitude about 10° farther to the south where the difference between winter and summer—the dark and the light time of the year—is by far not so pronounced as north of the Polar Circle.

(*j*) The direction of the electric currents has been dealt with already: The *W*-current predominates chiefly in the first part of the day and the *E*-current in the latter part. Of these two branches the one flowing towards east is slightly longer, especially from the northern Observatories. In the winter the *E*-current is relatively longer, in the summer the *W*-current, and also this variation is more distinct in the Observatories situated farther north.

Currents near the geomagnetic-axis pole—(*k*) The most surprising of the results of this investigation is the strong, chiefly vertical (at least apparently), isolated electric current flowing in the immediate vicinity of the magnetic-axis pole, detected on the basis of the magnetic diurnal inequalities from Godhavn and Thule.

This current has also two parts, namely, a separate forenoon and afternoon current. With respect to their time of appearance these currents correspond fairly well to the two branches of the currents along the auroral zone (Figs. 1, 4, 5, and 6), but they are oppositely directed. The horizontal component of the pole-current is rather small, but the vertical component all the more pronounced. This current seems to have a tendency to reach very great heights and intensities on the axis-pole itself. The average increase of the magnetic activity indicates the approach of this current to the axis-pole and increase of its intensity and height.

(*l*) The forenoon (*E*-) current flows on an average at a distance of about 1° past the axis-pole (Fig. 2). Its height and intensity (and the geomagnetic latitude of its horizontal projection) grow as the pole is approached and decrease again after the pole has been passed. The average intensity nearest to the pole on all days amounts to about 350,000 amperes, or amply the double of the maximum forenoon current of the auroral zone. On disturbed days (Fig. 3) the course of the current is at first similar to that observed on all days. After somewhat pulsating variations, it reaches its maximum intensity, over 700,000 amperes, near the pole, decreases then to some extent, but turns again a little later straight towards the pole, and, having attained a great intensity, disappears into very great height, or away from the Earth (if the current is considered positive). On quiet days the forenoon current is weaker and more indefinite than on all days on an average, but similar features may be observed in it, however.

The changes in the average magnetic activity thus appear distinctly in this current.

(*m*) The afternoon (*W*-) current is a powerful positive electric inflow—or equally well, a negative outflow—close to the magnetic-axis pole. It seems to belong to the afternoon electric-current system as a fairly regular phenomenon, which is similar in quiet magnetic conditions, but especially pronounced during greater activity. With the time of the day it moves continually nearer the axis-pole and higher from the surface. Its intensity attains a distinct maximum about one or two hours after local noon, decreasing again, but rising to a peak-value immediately before disappearing about 18^h local time. Then its intensity on disturbed days averages almost a million amperes.

(*n*) The maximum intensity of the afternoon pole-current occurs, as mentioned, soon after noon; here the presence of a solar effect can again be presumed. In Figure 6 attention is drawn to the fact that the shape of all intensity-curves in the Figures is largely similar. Likewise it is scarcely a chance coincidence that the maxima of intensity and height of the afternoon current, both of the pole and of the auroral zone, occur at the same local time. For this reason it seems evident that these two currents must have some kind of interrelationship.

It cannot be observed that the diurnal variations of the magnetic activity would be in any way reflected in the pole-currents.

(*o*) *The currents on quiet days*—The currents computed for selected quiet days are more indefinite than those determined for all days or especially for the disturbed days (Fig. 10-*A*). Their intensity is comparatively low, on an average less than 100,000 amperes, yet in axis-pole currents slightly more than this Figure. The auroral-zone currents found by the present method are concentrated chiefly on the day hours, and during the night hours only fragments of these currents can be observed. This confirms the fact observed in studying all days and disturbed days: That the day (more properly the afternoon) current is in a way a more permanent and regular phenomenon than is the night (forenoon) current. It seems very possible, although not quite clear on the basis of this study, that especially the night current is caused by the electric phenomena which in the last resort induce the magnetic disturbances or activity, but that the day currents must be regarded as more permanent features, conditioned in addition by the position of the Sun.

The currents of quiet days generally attain very great heights (Fig. 10-*B*), and it is observed also here that the intensity commonly increases with the height. The vertical component in the currents of quiet days is fairly pronounced, and a certain tendency of the currents to incline towards the magnetic-axis pole is clearly observed. In these currents the same circumstance appears which is noticed also in the currents of all days

and disturbed days, namely, that they are generally higher above the Earth's surface in the morning when they set in, than by night when they disappear (Figs. 8 and 9, top, and Fig. 10-*B*).

Conclusions—It is no doubt surprising that the currents computed according to the method used here are concentrated particularly in the two areas on the polar cap which have a peculiar situation from the geophysical point of view, that is, in the close geomagnetic-axis pole and along the auroral zone—and in these areas alone.

It may be that at those points where they disappear, according to the results obtained, the currents actually continue their course changing into a kind of surface current spreading over a wide area. On the other hand the whole pole-currents and the currents along the auroral zone, at least in their middle parts, seem to be concentrated into narrow ribbons, actually resembling the supposed line-current shape. Such concentrated currents are not to be found in other areas of the polar cap than those mentioned above (with the possible exception of some more-or-less indefinite currents on quiet days).

During magnetic disturbance the currents of the auroral zone expand outward and the pole-current approaches the pole, the intensity of all currents grows, and the maxima of the diurnal variation of the currents take place earlier; in addition the pole-current rises higher above the surface, but the currents of the auroral zone fall slightly lower. The influence of a disturbed period appears in changing of the average position and intensity of the current-system, but the very marked diurnal variation of the geomagnetic activity is very weakly reflected herein, or not at all. This shows that the whole current-system acquires another shape during the disturbed time, but that the diurnal occurrence of magnetic activity on the different meridians is also highly influenced by the Sun's position in the sky.

Of the fairly horizontal currents of the (symmetric) auroral zone the afternoon current towards east, seems to be more regular and permanent than the other branch. The same applies to the afternoon pole-current, which is in the main a strong positive inflow or negative outflow on the magnetic axis-pole itself. The Sun's position in the sky influences the pole-current and the afternoon branch of the auroral-zone current, but scarcely the forenoon branch of this current. The latter is most distinct on disturbed days and disappears almost completely on quiet days.

The connection between pole and auroral-zone currents is not revealed by this investigation. At least during a part of the day the forenoon current may be a closed current flowing over the axis-pole. The afternoon current of the auroral zone shows some features similar to the afternoon current of the pole; but taking into consideration the similarity of the variations in the pole-current during the forenoon and afternoon, it may

be connected with either of the current-branches of the auroral zone, perhaps with both at the same time.

The presence of powerful and concentrated electric currents flowing high above the surface along the auroral zone, readily directs the thought to a possible connection between them and auroras. The normal basic shape of auroras is a homogeneous quiet arc, which can be seen in the vicinity of the auroral zone almost regularly on clear evenings, if it has not acquired a ray-structure due to disturbances and moved farther south as a more luminous phenomenon moving chiefly upward and dispersed. During auroral display I have occasionally observed at Sodankylä that new quiet arcs have appeared above the northern horizon, auroras at the same time powerfully illuminating the southern sky. As well known, a homogeneous quiet arc gives the spectator the impression as if some extremely fine selfluminous substance would descend from very high on the sky; this substance increases in luminosity as it descends lower, until it is extinguished at a certain level over the surface, producing the strictly circumscribed lower edge of the arc, the so-called "black segment". An attractive assumption is that this falling "something" is originated by the strong electric current which fairly regularly flows—or at least has flowed—parallel to it above the arc.

I should like to finish by hoping that the reality, the true location, and the structure of polar-cap electric currents would be more closely studied by the aid of radiotechnical methods.

Meteorological Office,
Helsinki, Finland, February 1947

LETTERS TO EDITOR

(See also pages 174, 188, 232, and 263)

MEETING OF COMMITTEES *ANNALES DE GÉOPHYSIQUE*, NOVEMBER 8, 1946

The Patronage and Editing Committees of the *Annales de Géophysique* met November 8, 1946. There were present: MM. Barrabe; Cabannes; Cagniard; Chalonge; Coulomb; Goguel; Jouaust; Labrouste; Lanquine; R. P. Lejay; Tardi; Thellier; and Vassy. Excused were: MM. Bureau; Lacroix; Le Grand; Migaux; Rothé; and Vignal. Decisions adopted were as follows.

(1) Efforts will be made toward having the *Annales* take on a more clearly international character. The members of the Editing Committee will try, as opportunity occurs, to make known the review to their foreign colleagues. Articles will be published in French, English, or even German. The summary will always be in French. In addition to Professor Chapman and Dr. Jeffreys for England, and Dr. Fleming and Dr. R. P. Macelwane for the United States, scientists of other countries will be asked kindly to serve as correspondents. Foreign correspondents will assume the responsibility of the articles which they transmit, after having consulted, if they desire, the persons whom they judge competent.

(2) Articles not transmitted by foreign correspondents will be submitted to a member of the Editing Committee, who shall give his advice within two weeks. If he requests changes in the article, his report will be sent to the author in the name of the Committee, without mention of his name. In difficult cases, a second reporter may be consulted.

(3) The membership of the Committee appears satisfactory, except for Meteorology. The Director of the National Meteorological Service will be asked kindly to designate one of his collaborators to serve on the Committee.

(4) The representatives of the allied sciences (Geodesy, Geology, Cosmic Rays, etc.) will be requested to reserve for the *Annales* their articles of geophysical interest and to continue to supply periodical reports for the new heading "Rapports et Mises au Point".

INSTITUT DE PHYSIQUE DU GLOBE,
Rue Saint-Jacques 191,
Paris 5e, France, November 16, 1946

J. COULOMB,
Editor

HISTORICAL NOTES ON THE DEVIATION OF THE COMPASS

By W. E. May

Few historians of the magnetic compass carry their story beyond the period of the birth of ocean navigation. To those interested in this fascinating instrument there are, however, many interesting lines of enquiry to be traced in the centuries which followed. These notes are the result of an attempt to investigate the beginnings of just one branch of progress.

During the Sixteenth, Seventeenth, and Eighteenth Centuries, when there were many who tried to solve the problem of finding the longitude at sea, one of the favorite methods proposed was the use of the variation of the compass. Of those who proposed this method one of the last was Ralph Walker, a resident of Jamaica, who, in the year 1793, traveled to England* to lay his proposals before the Board of Longitude. It is not intended here to discuss his variation theory but to point out that, in addition to producing this theory, he designed a compass to enable the variation to be observed with greater accuracy at sea. This compass was sent for trial in H. M. Ships *Invincible*, *Glory*, and *Lynx*† and it was this trial in the *Glory* which introduced her master, Murdo Downie‡, to fame among those who have written on the magnetic compass. In his report on Walker's compass Downie wrote [see **1** of "Authorities quoted" at end of paper]:

> "It appears, that the variation observed at one view by Walker's compass, and that observed by the ship's compass by the bearing and altitudes, were generally very near the same. But it is evident, that the variations given by both compasses at different times and situations disagree very much: Whether any part of this disagreement may be owing to the time of the day the variations were taken, I cannot take on me to determine; but I am pretty well convinced, that the quantity and vicinity of iron in most ships has an effect in attracting the needle; for it is found by experience, that the needle

*Walker says that he took passage to England in H.M.S. *Providence* but I have been unable to find any record of him in her log or muster book. The *Providence* was commanded by the renowned Captain William Bligh and was then returning from his successful second bread-fruit voyage.

†Another compass was given by Walker to James Guthrie, the second lieutenant of the *Providence*.

‡Murdo Downie received an acting warrant as master to fill a vacancy in H.M.S. *Champion* in 1781. On the return of the ship to England three years later he passed as master of the fourth rate and his appointment was confirmed. He later, while still in the *Champion*, carried out surveys of the east coast of Scotland and, when publishing the results of these surveys, devoted a part of the introduction to his sailing directions to a warning against the evils of badly made compasses. He subsequently served in the *Defence*, *Union*, *Duke*, *Glory*, and *Resolution* and, in 1805, was reported medically unfit for sea.

will not always point in the same direction when placed in different parts of the ship: Also it is rarely found, that two ships steering the same course by their respective compasses will go exactly parallel to each other; yet these compasses, when compared on board the same ship, will agree exactly."

For the trials in the *Glory* the compass was usually placed five feet from "the iron stantions, or railing of the hatchway, leading to the wardroom" [**1**-*a*].

During the first half of the Nineteenth Century it was common for writers [**2**] to acclaim Downie as the first man to note that a compass might be deranged by the iron-work in a ship. However, an anonymous writer in the *Nautical Magazine* for 1837 [**3**] drew attention to a comment on the subject in the fourth (1700) edition of Captain Samuel Sturmy's *Mariners Magazine* and since that date others have come to light as the following quotations will show.

First in order of date we have the remarks of the great Portuguese navigator Dom João de Castro who, at Mozambique, on August 5, 1538* recorded the following:

". . . o ferro do qual berço chamava a si as agulhas e as fazia desviar desta maneira . . ."	". . . the iron of which (gun) cradles drew to itself the needles and caused them to deviate thus . . ." [**4**].

Next we have Gerrit de Veer, the chronicler of William Barentz third and last voyage in search of the Northeast Passage. On August 4, 1597, he noted that:

". . . we sailed along by the coast . . . supposing that we held our course west and by north . . . we were wholy deceiued by our compas, that stood vpon a Chest bound with yron bands, which made vs vary at least 2 points, whereby we were much more southerly then we thought our course had bin, and also farre more easterly . . ." [**5**].

In 1669 Captain Sturmy, to whom I have already referred, wrote [**6**]:

". . . The Points of the Needle or Wyres being touched by the Loadstone, are subject to be drawn aside by the guns in the Steerage, or any Iron near it, and liable to Variation."

Another sea-captain, Daniel Newhouse, a great admirer of Sturmy, wrote in 1685 [**9**]:

". . . you are to take great care there be no Iron at all near the Compass, nor to the Binacle, and that your Compass be not placed near Iron Guns, or other Instruments of Iron."

*The date of this entry is given as July 3 by Harradon, Some early contributions to the history of geomagnetism, Terr. Mag., **49**, p. 190 (1944).

I believe that there must have been some knowledge of the matter in France but the only passage of French origin which I have been able to trace occurs in a communication made to the Royal Society by de la Hire in 1687 [**8**]:

> "Too much reliance must not be laid upon the observations of pilots, by reason of the gross errors which it is not easy for them to avoid. For it often happens that near the space where the compass is, there is much iron, which draws the needle, and causes it to show a point on the horizon much different from what it would were it farther from the iron: which makes it appear as if there is considerable variation, where perhaps there is none at all."

It is obvious, from my next quotation, that the mathematicians William Mountaine and James Dodson knew that iron-work in the ship might deflect the compass for, writing nearly a century later, in 1758, they say [**9**]:

> "In making Observations, due regard should be had to the Station appointed for that purpose, that it may be as free as possible from the particular Attraction of contiguous Guns, Stantions or other Iron-Work."

These authors are almost certain to have been familiar with the work of William Whiston who, writing in 1721 [**10**] on the use of the dipping needle for finding the latitude and longitude, said that the instrument must be used in a place which "must have no Iron at all within a Foot or two; and no great Quantity of Iron within a Yard or two of it."

In the middle of the Eighteenth Century the Hamburgische Gesellschaft zur Beförderung der Künste und nützlichen Gewerbe was so dissatisfied with the German compasses of the day that it caused inexpensive copies to be made of the Gowin Knight compasses which had lately been introduced into the British Navy. With each compass it issued a leaflet of instructions and in this, probably issued in 1768, appears the statement [**11**]:

> "Es wird den Schiffern bekannt seyn, dass kein Eisen in der Nähe des Compasses sich befinden müsse."

> "The mariner will already be aware of the fact that no iron must be situated near the compass."

The celebrated captains Cook and Bligh seem to have had some inkling of the fact that iron would affect the compass. The former wrote, in 1777 [**12**]:

> "Whoever imagines he can find the variation within a degree, will very often see himself deceived. For besides the imperfection which may be in the construction of the instrument, or in the power of the needle, it is certain that the motion of the ship, or attraction of the ironwork, or some other cause not yet discovered, will frequently occasion far greater errors than this."

While at Teneriffe, in 1787, William Bligh recorded in the log of the *Bounty* [**13**]:

> "I am sorry I had no opportunity of making more Observations for the Variation of the Compass, for I had led myself to believe it did not exceed 15 degs: I could not help being more particularly surprised to find we had made it full 20 degrees. The weather had been remarkably Cloudy the whole Passage which has prevented me from making the Number of Observations I otherwise would, and most likely could have determined the Value of these Observations; but it is to be remarked that in Lat. 30° 52′ N. I found 22° Variation. Time and Opportunity therefore must determine how far my Compasses may be Affected by Iron in the Ship."

In spite of these remarks both officers appear to have been careless of their compasses for Captain Cook kept the keys of the leg irons in his binnacle [**14**] while Captain Bligh thought his binnacle a suitable stowage for a pair of pistols [**15**].

It is curious that the early commentators on Downie's report should have overlooked two other significant passages in Ralph Walker's pamphlet.

> ". . . it is a fact well known, that on board of all armed vessels, where there are great quantities of iron, the current of polarity is deranged in a very great degree" [**16**].
>
> If "there is a necessity for the binnacle being placed close to the commings of the after hatchway; where this is unavoidable, the bolts ought to be made of copper, because the iron bolts affect the needle of the compass. . . .
>
> "At any distance from the magnetic equator, the upper end of all iron bolts, &c. become possessed of a polarity of a different name with the latitude . . ." [**17**].

The construction of binnacles—A more particularised warning than those given above was expressed by the Sieur de Guillet in the latter half of the Seventeenth Century. He wrote in his *Dictionnaire* [**18**]:

"Habitacle . . . Il est fait avec des Planches assemblées par des chevilles de bois, sans qu'il y entre aucun ferrement, de peur que le fer n'ôte la direction naturelle de l'Aiguille aymantée du Compas de route, qui y est enfermé . . ."	"Binnacle . . . It is made with the planks held together by wooden pins, without any iron-work in it for fear that the iron deflect the natural direction of the magnet needle of the steering compass which is kept in it . . ."

Aubin, in his Dictionnaire de Marine of 1702, repeats this almost word for word and is followed by Saverien in his Dictionnaire of 1758 [**19**]. Their entries are curious in view of what they say on other pages and appear to indicate some confusion of thought. Aubin writes, and is closely followed by Saverien [**20**]:

"Balancier de Lampe. C'est un cercle de fer, qui est mobile, & qui tient la lampe de l'habitacle en équilibre."	Lamp Gimbel. This is a moving iron ring which keeps the lamp of the binnacle in equilibrium.

The British Navy Board was also concerned with the possible presence of iron in binnacles. On July 20, 1739, they issued an order to all dockyards that [**21**]: "The (compass) Boxes to be examined and in case any iron is found abouth them it is to be taken out and fastenings to be of brass".

Twenty years earlier the same Board had issued a rather similar order for the preservation of compasses when not in use [**22**]: "To be laid as far as possible from iron and in a dry place and to make a chest or box in ships to preserve them."

In 1749, Dr. Gowin Knight, whose compasses were soon to become the standard design for the Royal Navy, was consulted concerning the damage to the compasses of the ship *Dover* which had been struck by lightning. In discussing the case he said [**23**]: "It was natural to inquire if there was any iron about the binacle; but the Captain said he had given strict charge to the maker not to put so much as a single nail in it."

Interaction of compasses—Some writers mention that compasses will deflect each other if placed too close. In this connexion I quote Joseph Harris, a blacksmith turned teacher of navigation who had himself apparently served at sea [**24**]:

> "In large Ships where there are commonly two Men at the *Helm*, there is also placed two *Compasses* in the *Bittacle:* but I often observed that these two *Compasses* (when rightly placed) would differ from one another about ½ *Point;* which Difference the Sailors attributed to one being touched with a better *Load-Stone* than the other. But it is well known, that all *Needles* being rightly touched by any *Load-Stone* . . . will point exactly the same way; . . ."

The same fact is also mentioned, in 1768, in the German instructions for the use of compasses already quoted [**25**]:

"Die Schiffer haben die Gewohnheit zween Kompasse beym Steurruder in einem Gehäuse neben einander zu setzen, dadurch sie meinen desto sicherer zu fahren. Es haben uns aber verschiedene Proben gezeiget, dass ein Kompass noch in zeimlicher Entfernung auf den andern würke, und dadurch beyde aus ihrer Richtung gebracht wurden."	"It is a custom amongst mariners to use two compasses placed side by side whilst piloting a ship; it is thought that the course steered is then more accurate. But a large number of experiments have shown us that one compass affects the other even when at an appreciable distance; such that neither can be regarded as reliable."

A similar statement was made by William Hutchinson in 1794. This man, who had served in privateers and was dock master at Liverpool for many years, wrote [**26**]:

> "Some late observations, and several experiments which I have made myself relative to them, prove, that a very material error in the course may be occasioned by having two compasses, with needles of strong magnetic power, at the same time in the binnacle. For it is found by their action one upon the other, that they will vary, from two to three points from the truth, when suffered to stand too near to each other, a circumstance which it is very necessary a commander of a ship be apprized of, that he may be upon his guard."

Observers in the dark—The majority of the authorities I have quoted had, at one time or other, followed the sea and it might be assumed that the fact that proximity of iron to a compass would cause it to deviate was well known to the more skilful of the navigators of the Seventeenth and Eighteenth Centuries. Charles T. Beke, in a footnote in his edition of Gerrit de Veer's work, implies that this was so and that had Barentsz been still alive on August 4, 1597, so experienced a seaman would not have committed the error of trusting to a compass "that stood vpon a Chest bound with yron bands" [**27**]. There is, however, ample evidence that the fact of the existence of deviation was noted by several distinguished navigators without their associating it with the presence of magnetic materials.* It is possible that some movement of arms or suchlike cause was responsible for the sudden change in the variation experienced by Columbus on August 16, 1498, but he seems to have accepted it as just one of those things that happen at sea. His son recorded the incident [**29**]:

> "Medisimamenta dice, che quella stessa notte, che fu il Giovedi a XVI di Agosto non avendo fino allora norvestato, le aguglia norvestearono in fretta piu d'una quarta e mezza, e alcune mezzo vento, senza che in cio vi potesse essere errore, perdre sempre erano stati molto vigilanti per notar cio."

> "He (Christopher Columbus) also says that this same night, being Thursday 16th August (1498), the compasses, which till now had not northwested, did so at this time, at least a quarter and a half, and some of them two quarters, wherein there could be no mistake, because several persons had always watched to observe it."

Some noticed that unexplained changes of variation seemed to have something to do with the course of the ship. Norwood may have intended to hint at this when he wrote, in 1636, of the variation [**30**]:

*Edmund Halley, the great astronomer, stated that a ship's guns had no effect on the compass [**28**].

"He that is negligent or unskilful to observe it, especially in long Voyages and *various Courses*, may be led into many dangers by it."*

Dampier wrote, in 1699, during his New Holland voyage [**31**]:

"Another thing that stumbled me here was the Variation, which, at this Time, by the last Amplitude I had I found to be but 7 deg. 38 min. W.; whereas the Variation at the Cape [of Good Hope] . . . was then computed, and truly, about 11 deg. or more: And yet a while after this, when I was got 10 Leagues to the Eastward of the Cape, I found the Variation but 10 deg. 45 min. W. whereas it should have been rather more than at the Cape. These Things, I confess, did puzzle me: . . ."

Dampier admits to having read Captain Sturmy's book so should not have been quite so surprised.

Wales, who served as astronomer to Captain Cook during his second voyage of 1772-1775, also noted the existence of errors but though he gave some thought to the matter did not penetrate the truth. This is the more extraordinary in view of Cook's remarks quoted above. Wales wrote [**32**]:

"In the Channel of England, the extremes of the observed variation were from $19\frac{3}{8}°$ to 25°; and all the way from England to the Cape of Good Hope, I frequently observed differences nearly as great, without being able, any way, to account for them, the difference in situation being by no means sufficient. These irregularities continued after leaving the Cape, which, at length, put me on examining into the circumstances under which they were made. In this examination it soon appeared, that when most of these observations were made, wherein the greatest West variations happened, the ship's head was North and Easterly; and that when those, where it was least, had been observed, it was South and Westerly. I mentioned this to Captain Cook and some of the Officers, who did not at first seem to think much of it; but as opportunities happened, some observations were made under those circumstances; and very much contributed to confirm my suspicions; and throughout the whole voyage I had great reasons to believe, that variations observed with the ship's head in different positions, and even in different parts of her, will differ very materially from one another; and much more will observations on board different ships, which I now find fully verified, on comparing those made on board the *Adventure*, with my own made about the same time."

That these were not isolated cases is shown by yet another passage in Walker's pamphlet of 1794 and by a remark made by Admiral Sir John Ross, which, though made at a much later date, was written of the same period.

"The present Admiral Murray, and Captain Penrose, when cruising off the Ness of Norway, found that when the ship's head was in

*The italics are mine

shore, it made a difference of nearly a point in the compass, from what it was when the ship's head was off shore; and as many navigators as have been accurate in their observations, have taken notice of the same phenomenon in different parts of the world. By this remark it is not meant to insinuate, that such change in the direction of the needle was owing to any effect that the shore had upon it, but only, that by being in sight of the shore, an opportunity was had of ascertaining the fact." [**33**].

". . . in the year 1799 . . . in . . . H. M.'s ship *Weazle*. I could not satisfactorily account for the pilot constantly making an allowance for what he called in-draft when the ship's head was standing to the south-west, and none when the ship's head was standing to the north, with the wind in both cases from W.N.W.; yet he was always right in his reckoning." [**34**].

Compass errors attributed to load-stones—Many seamen observed apparent errors and concluded that different load-stones caused the needles with which they had been "touched" to point in different directions. Roger Bacon had put forward such a theory in his Opus Minus, in 1266 [**35**], and another instance of this belief is expressed by Fernando Columbus who says [**36**]:

"E, quanto al norvestare, io credo che la stella abbia la proprietà dei quattre venti, come l'ha ancora la calamita; che, se toccano col Levante, dimostrerà il Levante e altresi il Ponente, o il Settentrione, o l'Ostro; e pero colui che fa le aguglie copie con panno la calamita in modo che non resti di fuori, eccetto che la parte settentrionale, cioè quella che ha virtù di condurre l'acciaio a percotere la Tramontana."

"As to the northwesting, I believe that the pole star has the properties of the four winds, as has the lodestone; that when it touches the east, it will point to the east, and in like manner the west, north, and south; and for that reason, he who makes the compass-needle covers the lodestone with a cloth, all but the north point of it; namely, that which has the virtue of making the steel point to the north."

The same point of view was advanced by Richard Polter in his book *The pathway to perfect sailing*, written in 1586 but not published until 58 years later, while Joseph Harris refers to the belief as erroneous in the quotation given above.

Bad workmanship by compass makers—Of course many of the errors which were attributed to the use of different load-stones were really due to the infamous manner in which compasses were made. In 1750 Dr. Gowin Knight stated that of twenty cards [**37**]:

"He found them all to vary more or less, either to the east or west; and some of them as far as 8°. Few of them came to the same degree twice together; and when they did, that was never the true point."

This is by no means an isolated complaint. In 1616 Barlowe had written [**38**]:

> "The Compasse needle, being the most admirable and usefull instrument of the whole world, is both amongst ours and other nations for the most part, so bungerly and absurdly contrived, as nothing more."

Croker, in 1764, says much the same thing [**39**]:

> "The compass being of the utmost consequence in navigation, it is reasonable to expect that the greatest care and attention should be used in its construction, and every attempt to improve it carefully examined, and, if proper, adopted. But so careless are the generality of commanders of this most useful instrument, that almost all the compasses used on board merchant ships have their needles formed of two pieces of steel wire . . . if we examine a number of these cards, we shall rarely, if ever, find them all in the same direction, but they will all vary more or less, not only with regard to the true direction but with each other."

Flinders, in 1814 [**40**], described naval compasses as: ". . . the worst constructed instruments of any carried to sea," while even as late as 1820 we find Peter Barlow writing [**41**]:

> "Upon my examining the compasses in store in Woolwich dockyard, . . . I could scarcely bring myself to believe that the instruments exhibited to me were those actually employed in his Majesty's vessels: the cards, bowls, needles &c. seem all worthy of each other, equally clumsy and imperfect . . . they are, generally speaking, wretchedly defective, . . . and it does appear to me very unaccountable that vessels of such immense value, and the safety of so many valuable lives, should be endangered by the employment of instruments that would have disgraced the arts as they stood in the beginning of the 18th century."

Under such conditions few noticed any errors and in spite of the general knowledge that compasses were poor many trusted to them implicitly with disastrous results. A case in point was the tragic loss of H. M. S. *Apollo* and more than half of her convoy of 69 ships in the year 1804.

Lack of education among early navigators—The truth is that all through the centuries when British sea power was being consolidated navigators were a very ignorant lot. Few really knew more than the rudiments of their art. There were many treatises on the subject which should have helped them but the authors of these were mostly teachers of mathematics few of whom had any practical knowledge of the sea and who, rather than produce a serviceable little manual, preferred to pack out a bulky volume with numerous examples of mathematical calculations which, while quite useless to the mariner, served to testify to the apparent erudition of their authors. William Mountaine is particularly deserving of

censure for though he knew of possible compass errors not one word of warning did he insert into the several books of navigation which he revised [**42**].

It is a great pity that some of these writers did not take to heart Sir William Petty's notes on What a complete treatise of navigation should contain, which he wrote in 1685 [**43**]. Sir William had followed the sea in his youth and was, at one time, a Commissioner of the Navy. Among other details which a navigation manual should contain he lists: "The whole skill of the magnet, as to its directive virtues, and on the accidents which may befall it." It seems most probable from this that he knew that the compass needle might be deviated by the iron in a ship.

An occurrence narrated by Lionel Wafer illustrates the ignorance and superstition of many sailors in his age. In 1687 the *Batchelor's Delight*, a privateer commanded by Edward Davis and carrying Wafer as surgeon, called at Vermejo (Huarmey) in Peru. There they found a great cemetery of desiccated bodies and Wafer remarks [**44**]:

> "Of these Bodies I brought on board a Boy of about 9 or 10 Years of Age, with an intent to bring him home for *England*, but was frustrated of my purpose by the Sailors, who having a foolish Conceit, that the Compass would not traverse aright, so long as any dead Body was on board, threw him overboard, to my great Vexation."

It is not clear whether the throwing overboard of the body happened immediately or some time later but I think it likely that it may have been linked with what followed. Towards the end of the year Davis started to return round the Horn and in the latitude of 62° 30′ south turned northwards again, steering east-northeast and east by north as he was allowing three points westerly variation. Sights showed him that he was still making southing so he concluded that the variation was really easterly and altered course four points to port. Even then he was so far out in his reckoning that he made the latitude of the river Plate 500 leagues too far to the eastward and frightened his crew into thinking that they were still on the wrong side of South America and steering away across the Pacific. It is possible that it was during the uncertainty of the long run to the westward, in search of the land, that Wafer's curio was sacrificed to superstition. The variation south of the Horn was, at this date, about $2\frac{1}{2}$ points east and as Davis had come from the Pacific where the variation had always been easterly it is difficult to see how he had made his mistake otherwise than by sheer incompetence.

It remains an extraordinary fact that nearly 300 years elapsed between João de Castro's note on the effect of a ship's guns on the compass and the publication of Poisson's celebrated memoir on the theory of magnetism. During this period very few seamen knew that compass errors could be

caused by anything but the bad construction of the instruments. The individual errors of these were taken for granted.

The dawn of modern knowledge—It was left to Captain Matthew Flinders of the Royal Navy, at the beginning of the Nineteenth Century, to be the first individual to make a scientific investigation into the causes of the apparently extraordinary changes of variation which were encountered at sea. His conclusions were not entirely correct for he attributed the whole error to the effect of induction in vertical soft iron. All the same, his remarks on the subject were of the greatest value as he was the first to propose that navigation should be controlled, in each ship, from one particular fixed compass,* to lay down instructions for ascertaining the errors of the compass and to propose a method of correcting some part, at least, of the deviations.

The results of Captain Flinders' investigations were widely published and were commented on by many writers. In view of this publicity it is all the more extraordinary to note that there were still many who, either never suspected the errors to which their compasses might be subject, or were careless of them.

Bain, in 1817, quotes from a morning paper [**46**]:

> "*Caution to Navigators.* A Captain of a ship, lately on her passage from Bristol to Milford Haven, was much surprised to find that the course he was steering by compass was at variance with the well-known landmarks of the coast he was traversing. Several compasses were tried, but not one could be found that pointed north by two or three points. It was surmised by one of the passengers, that as the ship was laden with iron, it might have an effect on the needle. The compasses were moved to another part of the ship, and the experiment confirmed the surmise."

This quotation is all the more interesting as showing the merchant ship captain immediately attributing the error, when it was discovered, to bad manufacture of the compass instead of to any other cause.

Purdy, in his sixth edition of his *Atlantic Memoir*, published in 1829, says [**47**]:

> "In one of the letters of our friend Captain Livingstone, we find the following remarks:—
>
> 'It is strange with what pertinacity many maintain that iron will not attract the needle of a compass, provided the iron is covered with wood or puttied up. For my part, I am well convinced that many a fine ship has owed her loss to iron near the compass. It seems hardly credible, but it is nevertheless true, that I have seen more than one vessel with *copper-nailed decks*, and an *iron-fastened* binnacle!' "

*Some may cavil at this statement as Captain Bligh always made his observations for variation from one spot, the top of the binnacle [45]. There is, however, no evidence that he shaped his courses by other than the steering compass.

Captain E. Johnson, the first Superintendent of the Compass Department of the Admiralty, wrote [48]:

> "On inspecting a merchant steam-vessel which had been bought into her Majesty's service, finding the compasses were placed in a binnacle so closely together that they could not fail to produce serious errors by their reciprocal action upon each other, I requested the binnacle might be cut in two and the compasses separated. In this operation it was found that the binnacle itself had been put together with iron nails and screws; three quarters of a pound of the same having been extracted, and which are now in my possession: and in one instance the very box of the compass itself, which is placed inside the binnacle, had been repaired with iron nails!!"

Finally, in a footnote to an article in the *Nautical Magazine* of 1843 [49] discussing the wreck of the *Reliance*, an event rather famous in compass history which occurred in that year, the writer quotes a number of extracts from the press to show that merchant seamen were at last beginning to realise the danger of having iron near a compass. Truly, seamen in general had taken a very long time to appreciate the fact.

Deviation—It is not known when and by whom the expression "deviation" was first used to denote the error of the compass due to the magnetic effects of the ship. The earliest use which I have been able to find is by Captain John Ross, in 1819 [50]. Other writers of the period use such clumsy terms as "effect of ship's attraction", "effect of local attraction" (often shortened to the inaccurate term "local attraction"), "difference of variation", "deviated variation", and "aberration of the needle". By about 1840 the word "deviation" would seem to have become firmly established although Raper, in that year, tried to popularise the form "local deviation", discussing the matter in the following words [51]:

> "The term *local* is proper, because the needle is differently affected in different parts of the same ship, and in different places on the earth. The deviation is sometimes called *local attraction*, but the attraction is the cause, and the deviation is the effect, which alone is concerned in the practical result. The term local deviation is preferable to local variation, because the word *deviation* here relates solely to the action of the ship on the natural position of the magnetic needle; whereas, the term *local variation*, in strictness, implies the *total magnetic variation* of the compass at the time, which is made up of the true magnetic variation and the local deviation together."

The term "local attraction" is now sometimes used for the irregularity of the variation due to local causes met with in certain parts of the world [52].

Conclusions—From a study of the quotations given in this article I have come to the following conclusions:

Downie was not, as was at one time supposed, the first man to discover that a ship's compass might be deflected by the iron in her; the fact had been known since 1538, if not earlier.

Though this knowledge was fairly widespread it was not general, errors found being usually attributed to badly made compasses, use of varying types of load-stones, the attraction of the land, or simply to inexplicable causes.

Compasses were usually so badly made that instrumental errors often masked the existence of deviation except from the most scientific type of observer.

Of those who knew that iron might deflect a compass many thought that it could only act at a very short distance and then only if no other substance intervened.

The writers of books on navigation in the Eighteenth Century usually cared more for a display of mathematics than for the practical application of the art; hence, such knowledge as was available was not published.

The term "deviation" was adopted within a few years of the first investigations by Flinders having been made known and, in spite of alternatives, soon became general.

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[14] See [12] **2**, p. 103.

[15] See [13] **2**, p. 121.

[16] See [1](*a*), p. 14.

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[20] (*a*) See [19](*a*), p. 60.
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ADMIRALTY COMPASS OBSERVATORY,
Ditton Park, Slough, Buckshire,
England, February, 1947

LETTERS TO EDITOR

(See also pages 174, 188, 216, and 263)

SUGGESTIONS FOR REPRINTING ARTICLES OF HISTORIC INTEREST IN GEOMAGNETISM

I have two suggestions for the continuation of reprints of articles of historic interest in geomagnetism in the JOURNAL, as follows:

(1) Fr. Timoteo Bertelli did a great deal to clear up a number of obscure points in the history of terrestrial magnetism. Whatever he undertook, he carried out thoroughly, and, for the greater part, accurately. He made one or two mistakes—but we all do that. But I think his work, although widely mentioned, has not been properly appreciated, and I would suggest that the JOURNAL publish some account of his writings of which I do not know of a *complete* list.

(2) One of the best commentaries on the *Epistola* of Petrus Peregrinus was that written, about 1911, by Fr. E. Schlund, a Franciscan monk from Munich. It is published in *Archivum Franciscanum Historium* [**4**, 436-455 and **5**, 633-643 (1911 or 1911-12)]. This publication is issued in the interests of the Franciscan Order, and one can get in touch with its editors, or managers, wherever they may be by addressing La Directione, Archivum Franciscanum Historicum, Florence, Italy.

Schlund's article does not profess to deal with the scientific side of Perigrinus' work; his interests are mainly biographical. But this is frequently required. Apparently, however, the editors do not bother to see that their *Archivum* is properly circulated. The volumes I have referred to are to be found only in one library in this country, except the British Museum and the Bodleian at Oxford.

I suggest that permission might be obtained from the Editors, above, to republish Schlund's articles and also (if they have them), to send you one or two off-prints. The articles are written in German, and it would be better to get them translated into English. That will have to be done with great care, for the author has not condescended to make perfectly clear what he means by certain references. But that the articles are of great value is evident when one sees them.

51 Merchiston Crescent,
Edinburgh, Scotland, January 6, 1947

A. CRICHTON MITCHELL

THE SUNSPOT-CYCLE BEFORE 1750

By D. Justin Schove

Sunspot-numbers since 1749 form [Wolf, 1945] a long and reliable series of indices with an obvious but unexplained 11-year cycle (see Fig. 1). Harmonic analysis has hitherto proved unsuccessful in extending the series forward into the future. Even the first decimal place of the length of the cycle is in dispute and it has been suggested that at times a ten-year or smaller cycle replaces the normal one (compare Zeuner, 1946, p. 16, etc.) The predictions of 25 years ago are already out of phase with actuality and, even as regards the immediate future, experts disagree. Shapley (1944) in the United States of America predicts a maximum in the year 1949.6 with a value of 80 whilst Waldmeier [1946*a*] at Zurich anticipates an intense early maximum in 1947.6 with a value of 139. A formula for monthly forecasts in the more immediate future is given by Stewart and Eggleston [1940].

Gleissberg at Istanbul, Voigt, Holtzhey [1940], Inigo Jones, and others have elaborated theories purporting to explain the irregularities. Thus Gleissberg [1945] considers that the cycle-length varies consistently after every seven cycles in a cycle of its own. Voigt [1928] gives a chart (Chart XV) by which the planetary influences of Neptune, Uranus, Saturn, and Jupiter ingeniously combine to give an admirable imitation of the sunspot-curve for 1749-1928.

Progress in understanding the mechanism of sunspots has been reviewed by Waldmeier [1946*b*], but the test of all theories of the periodicity must ultimately lie in prediction. The next sunspot-maximum would not itself be decisive, but extrapolation into the past could and should be made. If medieval epochs can be deduced according to any planetary or other theory, they could be compared with those obtained inductively. I have accumulated, as by-products of a collection of meteorological chronologies, a large number of records of auroras and sunspots, which will enable epochs to be determined with fair accuracy.

Many pre-1749 epochs were estimated by Wolf and Fritz, whose results are those generally quoted. Their analysis was however, somewhat uncritical and was fitted somewhat arbitrarily into an 11-year scheme. They assessed the evidence according to the following order of significance: (*A*) Sunspots; (*B*) auroras; (*C*) hail; and (*D*) wine harvests.

We now know [compare Brooks, 1934] that, at least in Central Europe, from where Fritz secured his data for hail, that thunderstorms and sunspot-maxima are not in phase. The wine-harvest data are related to the hail rather than to the sunspots so that sources (*C*) and (*D*) must be discounted as evidence for (*A*). The many investigations of Clayton, Schostakowitch,

and Abbot lead one to the conclusion that at least in temperate latitudes, the magnitude of the effect of weather is slight; even in the tropics the oft-quoted correlation-coefficient of 0.8 between sunspots and the level of Lake Victoria has been invalidated by subsequent events. Stetson's stimulating book makes interesting reading, but his correlations do not apply historically. O. Pettersson attempted to make sunspot-periods fit in with the Swedish herring fishery but his "periods" in each case were "deduced" and artificial.

Meanwhile, since Fritz and Wolf published their results, much new information has come to light. Dubs [1944] found the Chinese observed, with the naked eye, sunspots as long ago as 25 B.C., but some of their later observations (for example, 1370-71 A.D.) as given by Hosie and Fritz seem suspect. Some of the so-called "auroral" displays were more probably shooting stars, but hitherto unpublished auroral evidence has now appeared from Russia, Hungary, Holland, China, and Japan. It is particularly interesting to find Buddhist prayers against "Holy Clouds" in Japan (for example, 765 A.D.) synchronising with what are obviously auroras in the Irish Annals. Such events will be discussed further in my forthcoming book [Schove, 1948].

As regards the major trends of solar activities it has been necessary to eliminate "strong" and "weak" periods which are so in virtue merely of the richness or poverty of the record. Thus there is an abundance of records in the first half of the Ninth Century associated in Europe with the Carolingian renaissance; but a century later records are poor. The main periods of solar activity do not fit into the schemes of O. Pettersson and others.

In the light of the above information I have prepared a revised chronology of observations of sunspots and auroras up to 1749 A.D.

The sunspot-period and terrestrial phenomena—Many biological cycles were formerly thought to be linked with sunspots. Elton finds that these, notably one of 9-2/3 years, are very real, and has used them successfully in predicting fur-trade returns. These cycles Elton* shows are related neither to cycles of sunspots nor weather, but are an implicit rhythm in the

*In referring to the biological cycle of 9-2/3 years, C. S. Elton reminds me that I have not expressed his view correctly. "The showshoe-hare cycles" he writes, "tend to develop their peaks in the same sequence every time across Canada, and there do not seem to be enough predators or signs of pandemic disease to account for this on the Volterra theory. Moreover, species like the muskrat living in the water and unconnected with the snowshoe-rabbit have the same length of cycle. This indicates that some climatic factor probably helps to keep the regional rhythm in step."

Ellsworth Huntingdon in his "Mainsprings of civilization" [1945, New York] discusses the same cycle in Chapter 25 and the claims of ozone to be the causative factor. He notes [p. 496]: "Many observers have found a cycle of about nine years and another of about ten in sunspots." As far as the post-1750 values are concerned this would require a tendency for the solar cycle to appear shorter in its stronger 33-year groups, and for this there is no evidence. The two phenomena are evidently independent.

ecology of the species in consideration. Ecological cycles, rather than sunspot-cycles, doubtless account for many relations with epidemics, etc., noted by Tchijevsky (Chizhevsky) and Chappelain. The mathematical theory of such cycles is presented in a recent book by Umberto d'Ancona [1942].

Earthquakes and volcanoes however, have been found to show a suggestive linkage with sunspots, although it is odd that Davison [1938] should find the mean cycle (since the Fourteenth Century) to be just *under* 11 years. In the last two centuries, apart from certain isolated regions (notably Japan), earthquakes are more likely to occur near years of the form (1709 + 11n), that is, normally years of waning sunspots. In the language of the letter-code, to be outlined below, this is equivalent to a statement that earthquakes have more often occurred around h-years; this is some three years later than the sunspot-maxima, which, on the average, over the same period, have occurred around e-years.

Dendrologists in America, by a method admirably described in Chapter 1 of Zeuner's book, have discovered the solar cycle in tree-rings, and have, moreover, noted certain anomalous variations in the period 1645-1715 and in the Fifteenth Century.

Revised values of early epochs—In the light of the above discoveries, I am using my chronologies to revise the earlier Wolf-Fritz dates of sunspot-epochs, assessing my evidence in the following order of significance (I have deliberately considered auroras as better evidence for sunspots than the sunspot-observations themselves, on account of the sporadic observations of the latter): (B) auroras; (A) sunspots; (E) tree-ring analyses; (F) earthquakes; (G) meteorological phenomena (for reference not evidence); and (H) shooting stars (to be discounted where previously classified as auroras).

I should be interested to receive new evidence of any of the above varieties and pleased to make comparisons between new material and that already collected. I hope to publish shortly "epochs" (as defined below) of sunspot-maxima for each third of a century (that is, three periods of 11 years). In the meantime it would be an interesting test if these epochs could be extrapolated before 1749 on the basis of different theories of the sunspot-cycle.

Epoch determination—Pre-1750 data do not warrant any more precise treatment than the following rough and ready definition of "epoch" given below.

The data (auroras, tree-rings, earthquakes, etc.) are first summed in groups of three at 11-year intervals. These sums are denoted by small letters. As an example let us write (01) as indicating the number for a year ending 01; we then have for the opening third of a century: (01) + (12) + (23) = a; (02) + (13) + (24) = b; . . . . ; (11) + (22) + (33) = k. For the last third of any century it is best to write (67) + (78) + (89) + (00) = $4a/3$. This scheme enables us to use every year of the century and at the same time to use a similar method for each century.

Whichever of these small letters has the greatest value is called "m". Where sunspots or auroras are in consideration the 11-year period is usually already apparent in the curve of these sums.

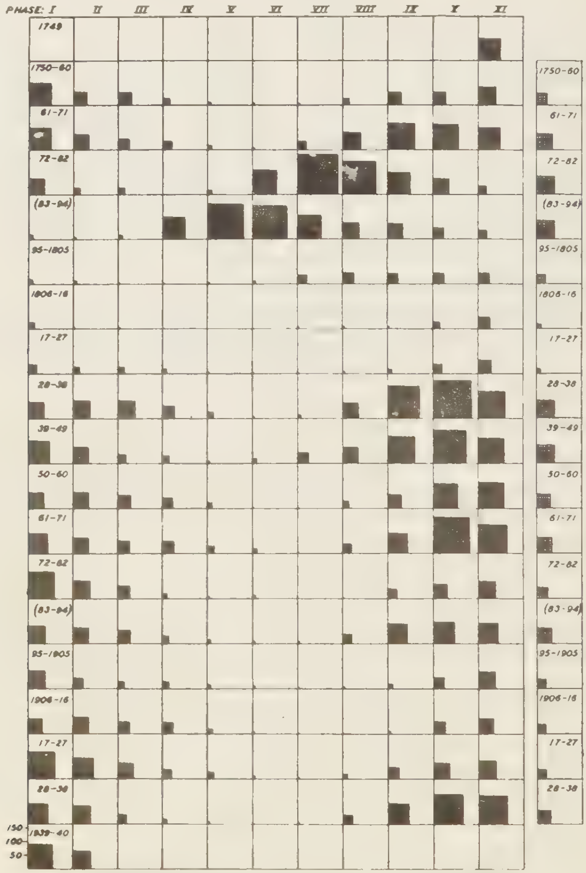

FIG. 1—ANNUAL NUMBER OF SUNSPOTS DURING 17 CYCLES, 1749-1940 (AFTER A. THRAEN)

These eleven sums $a, b, \ldots k$ are then further summed by moving five; year periods as follows: $a + b + c + d + e = C; b + c + d + e + f = D$- .... ; $k + a + b + c + d =$ B.

If an 11-year period is genuinely present it should be revealed by a sine-form of these eleven sums $C, \ldots B$. Whichever of these has the greatest value is called "M"; this "M" is our rough and ready definition of the epoch. These processes can be followed more readily by studying Tables 1 and 2 of this paper. The reader who has available 33 years of data is recommended to prepare a table similar to Table 1.

TABLE 1—*Example showing the determination of indices a, b, ⋯ k, and A, B, ⋯ K from sunspot-numbers of the first third of the Twentieth Century*

Period	Phase-year No.										
	1	2	3	4	5	6	7	8	9	10	11
1901-1911	3	5	24	42	64	54	62	49	44	19	6
1912-1922	4	1	10	46	55	104	81	64	39	25	15
1923-1933	6	17	44	64	69	78	65	36	21	11	6
Sums	13	23	78	152	188	236	208	149	104	55	27
= Index	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
Sums moving 5-year periods	196	293	454	677	862	933	885	752	543	348	222
= Index	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*

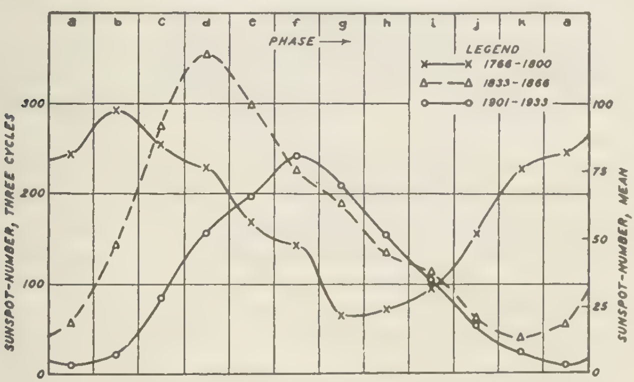

FIG. 2—THE SUNSPOT-CYCLE IN EIGHTEENTH, NINETEENTH, AND TWENTIETH CENTURIES
(TENDENCY FOR PROGRESSION FROM LEFT TO RIGHT OCCURS INSOFAR AS THE CYCLE IS GREATER THAN 11.1 YEARS)

The presence of the 11-year cycle will, in the present investigation, be assessed from the consistency of this "epoch" M. Correlation of tree-rings, earthquakes, etc. can be tested by comparison with Table 2, based on sunspot-numbers since 1767. (First legend of Fig. 2 should read 1767, not 1766.)

Auroral observations give almost identical results.

It will be noticed that usually M is more advanced in the alphabetic cycle than m, a fact which follows from the skew shape of the usual 11-year wave [compare Thraen 1941, or Waldmeier, 1946*b*], the rise being rapid and the fall prolonged.

It will also be apparent that calculated in this way, m and M tend to progress forwards or backwards through the alphabet according as the solar

Table 2—*Epochs of sunspots, 1767-1933*

33-year interval	m	M
1767-1800	b	B
1801-1833	e	F
1834-1866	d	E
1867-1900	d	E
1901-1933	f	F

cycle tends to be longer or shorter than 11.1 years. Such a table will be extended in another article into the Middle Ages on empirical evidence, but I hope that meanwhile others with theories of the solar cycle will attempt to prepare such a table on deductive grounds. In this way a true test can be arranged.

The above method of determination of epoch can be used for all series of data which show a periodicity of about 11 years.

In conclusion I should like to express my thanks to Professor R. E. Zeuner, Dr. C. E. P. Brooks, and C. S. Elton for valuable suggestions.

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St. David's College,
Beckenham, Kent, England, November 10, 1946

CURRENTS OF ATMOSPHERIC ELECTRICITY

By J. Alan Chalmers and E. W. R. Little

Summary—An account is given of recordings of vertical electric currents in the atmosphere from November, 1938, to August, 1939. General results are given and some special phenomena analysed in detail.

(1) *Introduction*

The present paper is an account of measurements made at Durham during November, 1938, to August, 1939. The delay in publication has been caused by the preoccupation of one of the authors with war work. The results of one day's measurements have already been discussed [see Chalmers and Little, 1940, under "References" at end of paper], and a note has also been published regarding the very large currents during a shower of soft hail [see Chalmers and Little, 1939].

(2) *Vertical electric currents*

The transfer of electric charge to and from the Earth through the atmosphere takes place by four processes: (*a*) Conduction by the normal ions; (*b*) precipitation; (*c*) point-discharge; and (*d*) lightning-flashes. In the discussion, it is convenient to consider the quantities of charge, positive and negative, flowing to one km of the Earth in a year by the different processes.

Wormell [1930] made measurements which suggested that there is a rough balance in the quantities of charge brought down by the different processes over a year at Cambridge.

Measurements are here described by which the quantities of charge brought to an isolated area by conduction and precipitation have been obtained. Also the point-discharge through a single point has been measured simultaneously.

For the measurement of the total quantities of charge received by the Earth by precipitation, it is obviously of advantage to use an exposed portion of the Earth's surface, rather than a shielded receiver such as has been used in most measurements of precipitation-currents. With a shielded receiver, care is taken to prevent any effects of splashing, whereas under natural conditions splashing will occur and might alter the quantity of charge received by the Earth. Also a shielded receiver cannot catch all the rain during wind and it is possible that the rain caught is not a fair sample from the electrical point of view; Scrase [1938] in his measurements caught only half the rain measured in a standard rain-gage. Wilson [1916] appears to have been the first to suggest the advantages of a completely exposed receiver, but did not attempt the method; Schonland [1927] and Wormell [1939] have used the method for short periods, during thunderstorms, only.

(3) *Apparatus for current-measurement*

The apparatus used consists of a wooden tray of area 0.98×10^4 cm^2 (nearly one meter square), lined with zinc to make it watertight and having a plug to allow water to be drained out. The tray is 12 cm deep and is fitted with a wooden false bottom which supports a layer of earth in which grass similar to that in nearby fields is allowed to grow uncut. This collecting surface is mounted on four insulators of sulphur, electrically heated to maintain dryness. Metal receptacles are hung from the tray to collect rainwater which drips off after running down the inclined sides of the tray.

Ideally, the apparatus should be placed in a flat field and surrounded by similar grass, but this was not possible under the conditions existing and the apparatus was placed on the flat roof of the Durham University Science Laboratories, and surrounded with a "guard-ring" of similar grass, of width 30 cm and separated from the collector by a gap of about $2\frac{1}{2}$ cm.

The collecting surface is connected by means of a lead-covered cable to one side of a $\frac{1}{2}$-microfarad condenser, the other side being connected to earth; it is found necessary to keep the rubber insulation at the upper end of the cable warmed by a heater, for otherwise there is a large spurious effect (probably caused by contact-potential between the lead and copper), whenever moisture condenses on the rubber. Figure 1 shows the apparatus in situ.

By means of clockwork mechanism, the condenser is discharged at regular intervals (approximately ten minutes) through a high-sensitivity ballistic galvanometer and the deflection is recorded photographically by a drum camera. All the charge received by the surface during the ten-minute period is stored by the condenser and then discharged through the galvanometer. In order to increase the damping of the galvanometer, a resistance is kept across the terminals and, to give different sensitivities, parts are used in series and parts in parallel. Table 1 shows the arrangements for the three sensitivities.

Table 1—*Arrangements for three sensitivities*

Sensitivity	Series resistance	Parallel resistance	Average current for 1 mm defl'n
	ohms	*ohms*	*amp/cm²*
High	......	222,000	1.00×10^{-16}
Medium	211,000	11,000	23.04×10^{-16}
Low	221,000	435.2	554.7×10^{-16}

When the deflections obtained are larger than can be recorded on the camera, the current can be measured from the reverse deflection, and it is

found that the ratio of successive deflections is 3.80 to 1, and this is the same for all the sensitivities, since there is the same resistance across the terminals of the galvanometer; as is occasionally necessary, the third deflection can be used. The "gap" in the zero-trace shows with certainty how many deflections off the scale have occurred.

Unfortunately, it is not always possible to judge the correct sensitivity to use, and some recordings are lost owing to the galvanometer being left on too high a sensitivity and sticking, while on other occasions it may be left on a low sensitivity, giving deflections too small for measurement. In

FIG. 1—EXPOSED COLLECTOR FOR CURRENT-MEASUREMENT

other cases, the records are obviously faulty, and this can often be traced to electrical leakage over the insulation, over spider-webs (which were regularly looked for and removed) or over grass crossing the gap between the collector and the guard-ring. Another cause of faulty records is a leakage of water from the tray, when drops can carry charge from the collector, and this charge gives a spurious effect depending on contact-potentials. As a result of these faults, a complete series of measurements was not obtained.

A daily test of insulation is made and on the average it is found that the loss of charge over a period of ten minutes is about two per cent, so that there is only a correction of one per cent for leakage to be made to the

Fig. 2—POINT-DISCHARGE-AND-CURRENT APPARATUS

observed currents. This low rate of leak is achieved by reason of the large capacity of the condenser, so that the potential-difference between the collector and earth is always small. Under these conditions, the current through a high insulation resistance (10^{11} ohms) is very low. An added advantage of the use of the large condenser, so that the collector never attains a potential much different from Earth, is that there is little distortion of the field; the highest currents observed are of the order of 10^{-12} amp/cm^2, so that the collector is at a potential of only about 20 volts different from Earth; since the fields are also high under such conditions, this represents the potential at a position only a fraction of a centimeter from Earth level. In the case of the fine-weather current, of the order of 10^{-16} amp/cm^2, the potential acquired is only of the order of millivolts.

In the discussion, this apparatus will be referred to as the "galvanometer-apparatus" to distinguish it from other measurements.

(4) *Apparatus for point-discharge*

For the measurement of point-discharge, a platinum point is supported, insulated by means of paraffin wax sheltered from the rain, on a pole attached to a projection above the building, so that the point is three meters above the projection and six meters above the general level of the roof. A lead-covered cable connects the point to Earth through a galvanometer; by means of a shunt, two different sensitivities are available: "High" sensitivity, with one-mm deflection corresponding to 0.0624 microamp and "low" sensitivity, with one-mm deflection corresponding to 0.520 microamp. To obtain the total quantity of charge passing through the point, the areas on the records can be measured and one mm^2 represents 6.8 microcoulombs and 56.5 microcoulombs, respectively. The point-discharge is recorded on the same drum as the current, but recordings are

often not obtained, since, usually, there is no point-discharge. Faulty records of the point-discharge are very rare and occur only through some misadjustment of the apparatus. Figure 2 shows the lay-out of the apparatus.

(5) *Auxiliary measurements*

On a few occasions, measurements were made of the charges on single drops, by the method used by Chalmers and Pasquill [1938], at the same time as the galvanometer-apparatus was in use, and thus a comparison could be made between the currents to the exposed collector and those obtained from the single drops.

During the two months of May and June, tests were being made, also on the roof of the building, with apparatus similar to that used by Scrase [1933] for the measurement of the air-earth current and the vertical field. To distinguish the current-measurements made by this method from those made by the galvanometer-apparatus, this will be referred to as the "electrometer-apparatus".

It was not possible to measure the amount of rain received by the collector, and no measurement of rainfall was made at the same place, but records of rainfall at Durham Observatory, one-half mile away, were available and have been used to obtain the approximate times and rates of rainfall.

(6) *Effect of field-changes*

In Scrase's [1933] method of measuring the conduction-current, any change of field is compensated and produces no apparent current. The usual shielded receiver for precipitation-currents also shows no effect of field-changes.

But the galvanometer-method, with an exposed receiver, gives an apparent current if the field is different between the beginning and end of the ten-minute period of collection. The "bound" charge on the surface of the collector is given by $F = -4\pi\sigma$, the negative sign signifying that the bound charge is negative in a positive field. If the field increases, the negative bound charge is increased and this appears as an additional positive charge on the condenser and so as an apparent positive current to Earth. If the field changes by 60 volts/meter = 1/500 ESU, the bound charge alters by $1/2000\pi$ ESU/cm^2 = $4.9/\pi$ ESU over the area of the collector = $4.9/3\pi \times 10^{-9}$ coulombs, corresponding to an average current over the ten-minute period of 0.83×10^{-16} amp/cm^2. This is of the same order as the fine-weather current, and thus individual measurements of current over ten-minute periods cannot be accurate if there are field-changes of the order of 60 volts/meter. However, if the results are averaged over an hour, the corresponding error is likely to be reduced.

The apparent current due to field-changes is the price to be paid for the advantages in using a completely exposed receiver.

(7) *Results for total current*

The total quantities of electricity collected have been added for the different months and are shown in Table 2, the figures denoting coulombs per km^2.

Table 2—*Total quantities of electricity collected*

Month	Positive	Negative
	coulombs/km²	*coulombs/km²*
November, 1938	3.6	1.4
December, 1938	58.8	74.4
January, 1939	39.4	25.0
February, 1939	4.0	0.9
March, 1939	9.7	8.5
April, 1939	14.5	10.4
May, 1939	3.6	2.3
June, 1939	12.0	13.6
July, 1939	76.3	14.0
August, 1939	5.8	5.2
Totals.........	227.7	155.7

This gives a positive balance of 72 coulombs, but, before this can be accepted as being the total charge received in the period, it must be realised that a very large portion of these 72 coulombs is due to precipitation covering a very short period of time, and, for the causes mentioned above, it is likely that periods with similar current have been missed. Table 3 gives the

Table 3—*Quantities of electricity received on days when currents were excessively large*

Date	Time	Positive	Negative	Remarks
1938-39	*h m h m*	*coulombs /km²*	*coulombs /km²*	
Dec. 19	11 30-13 20	20.6	54.3	Soft hail (− 43.8 from $12^h\ 56^m$ to $13^h\ 06^m$
Dec. 20	11 00-24 00	30.2	13.8	Soft hail
Jan. 2	04 00-12 00	15.0	9.9	Rain, snow, and sleet
Jan. 27-28	14 00-12 00	13.8	5.0	Snow and hail
July 9	15 20-16 50	63.0	0.0	Thunderstorm
Totals..................		142.6	83.0	....

quantities received on those days when the currents were exceptionally large.

If these five days were omitted, the total balance would be only + 12.4 coulombs.

It is clear that before any certain conclusion can be reached as to the total charge received by an area of the Earth due to conduction and precipitation, it is necessary to have complete records extending over a number of years. Scrase [1938] reached a similar conclusion from his measurements of rain-currents over two years, when the total charges for the two years differed very widely.

(8) *Conduction-current*

The measurement of the conduction-current in fair weather is not as accurate by this method as by the method of Scrase [1933], by reason of the effect of field-changes, but the results obtained are worthy of record.

All the records were measured and tabulated, and, to obtain the fair-weather current, all observations were rejected which gave average currents of over 10×10^{-16} amp/cm^2. Also observations were rejected which gave more than one negative discharge within an hour and those in which it was known that there was precipitation. The remaining observations in each month were grouped together in hours, but there is insufficient evidence for any definite variation with time of day, probably because there were toc few observations available for some of the hours. The values for monthly averages appear significant and are given in Table 4.

TABLE 4—*Monthly averages of fair-weather air-earth current*

Month	Current	Month	Current
	amp/cm²		*amp/cm²*
November, 1938	2.0×10^{-16}	April, 1939	1.5×10^{-16}
December, 1938	2.4×10^{-16}	May, 1939	1.7×10^{-16}
January, 1939	2.8×10^{-16}	June, 1939	2.5×10^{-16}
February, 1939	2.1×10^{-16}	July, 1939	3.3×10^{-16}
March, 1939	1.8×10^{-16}	August, 1939	3.3×10^{-16}

Neglecting the possible effects of the two missing months, this gives an average air-earth current of 2.3×10^{-16} amp/cm^2. To convert this to a correct value for level ground, it would probably be necessary to reduce it somewhat, since it is likely that lines of force and of current-flow will tend to be concentrated on the flat roof of the building; the probable value of the true current is around 2×10^{-16} amp/cm^2, to be compared with Scrase's value of about half this at Kew. This difference is important, since both sets of measurement are by the "direct" method, and while the measurements

at Kew give about half the value obtained by the "indirect" method at other places, the Durham measurements are in general agreement with results by the "indirect" method. The difference is not, as was at one time suspected, due to a difference of method, but due to the local conditions at Kew. That the two methods do give the same results has already been established by Nolan and Nolan [1937].

The annual variation, with a maximum in summer, agrees with that found by Scrase, but the minimum in April (and presumably also in October) differs. It must remain for further work to establish whether the spring minimum is a definite feature of Durham conditions or whether it is a peculiarity of the year considered.

(9) *Point-discharge*

The areas on the records for point-discharge were measured and the monthly totals are given in Table 5 in millicoulombs.

Table 5—*Monthly totals for point-discharge*

Month	Positive	Negative
	millicoulombs	*millicoulombs*
January, 1939	38.0	44.8
February, 1939	0.9	0.8
March, 1939	17.4	20.6
April, 1939	12.1	15.9
May, 1939	0.8	3.5
June, 1939	6.6	8.7
July, 1939	17.8	28.1
August, 1939	9.3	17.4
Totals.......	102.9	139.8

This gives a negative balance of 36.9 millicoulombs and a ratio of negative to positive of 1.36. For comparison, Whipple and Scrase [1936] found for the same months of the years 1933 and 1934:

1933, $+77.5$ and -135.0, ratio 1.74
1934, $+69.3$ and -117.2, ratio 1.69

It is noticeable that the Durham ratio of 1.36 is much less than the Kew ratio, but further measurement will be needed to establish whether this is a peculiarity of the place of measurement or of the particular year.

If it is assumed that the separation of points similar to the one used is

the same as that estimated by Whipple and Scrase [1936] for Kew, namely a separation of 25 meters, then there will be 1600 such points in one km^2 and thus the total charge received per km^2 in eight months is -59 coulombs or about -90 coulombs per year.

(10) *Rain-currents*

It is not possible to give definite figures for the total charge brought to the Earth by rain, for various reasons. In the first place, it is not always certain when rain was falling, because the apparatus indicates conduction-currents as well as rain-currents; with a shielded receiver, it is only when there is precipitation that there can be recording of charge, but this does not hold with the exposed receiver. Again, if there is a large field-change, this appears as a current and it is not possible, from the records, to determine whether a particular deflection is due to rain or not. From the total quantities of charge received, it is possible to conclude that precipitation brought a positive charge to the Earth on the balance for the periods observed.

In order to discuss the results for rain-currents, it is preferable to collect certain examples of different kinds of rain and discuss these separately.

Because of the fact that the effects on single days are more important in the totals than the sums for many other days, it is difficult to draw many very definite conclusions, in view of the missed or faulty records on some occasions.

(11) *Continuous rain*

From the records it has been possible to extract a number of cases in which there was continuous rain over a period of at least three hours and during which time the records were complete. These are shown in Table 6.

From Table 6 it can be seen that the charge on continuous rain shows a seasonal change; if the entries in the Table are divided after April 4, it will be seen that nearly all the earlier entries show positive excess and nearly all the later entries show negative excess. The point-discharge, and therefore the field, is negative in most cases, both in winter and in summer.

Chalmers and Little [1940] have discussed the period March 27-28, which gives the greatest positive-to-negative ratio, in some detail and have shown that there are two possible explanations of the results: (*a*) Either there is a separation of charge in the cloud, giving positive precipitation and leaving behind the negative charge which produces the negative field; or (*b*) the negative field is set up, and the precipitation obtains its charge by the capture of ions, through the process suggested by Wilson [1929], while falling. Neither of these explanations can account for the change from winter to summer conditions.

TABLE 6—*Recorded cases when there was continuous rain over at least several hours*

Date	Time	Positive	Negative	Av. rainfall	Point-discharge
1939	*h m h m*	*coulombs /km²*	*coulombs /km²*	*in/hr*	
Jan. 14-15	21 00-02 00	0.16	0.07	0.05	Slight positive
Jan. 17	01 00-04 00	1.77	0.04	0.01	2 short negatives
Jan. 17	18 00-24 00	0.12	0.11	0.03	Slight both
Jan. 20	03 00-06 00	0.12	0.05	0.03	Slight both
Jan. 21	09 00-21 00	0.02	0.25	0.02	Negative in positive rain
Feb. 3	01 00-08 00	0.05	0.01	0.005	None
Feb. 22	01 00-07 00	0.26	0.09	0.015	Slight both
Feb. 28	07 00-11 00	0.26	0.14	0.05	Some negative
Mar. 11	13 00-20 00	0.71	0.10	0.04	Both, mainly positive
Mar. 16	09 00-13 00	0.03	0.04	0.005	None
Mar. 27-28	13 00-06 00	1.27	0.02	0.04	All negative
Mar. 28-29	10 00-07 00	0.99	0.20	0.025	Nearly all negative
Apr. 4	04 00-11 00	0.56	0.13	0.015	None
Apr. 23	15 00-20 00	0.00	0.08	0.02	Slight both
Apr. 24	16 30-20 00	0.47	0.68	0.03	Mainly negative
May 1	03 00-07 00	0.01	0.04	0.002	None
May 5	16 00-23 00	0.10	0.12	0.02	Slight negative
May 14	01 00-08 00	0.12	0.02	0.015	Some negative
June 16	00 00-05 00	0.02	0.51	0.03	None
June 19-20	22 30-04 00	0.15	0.16	0.06	Negative
July 6-7	21 00-02 00	0.06	0.06	0.025	None
July 28	06 00-09 00	0.03	0.06	0.02	None
July 31	12 30-16 20	0.14	0.74	0.02	Both, mainly negative
Aug. 3	00 00-14 00	0.15	0.84	0.065	Nearly all negative
Total..................		7.57	4.56	....	....

(12) *Showers*

To extract showers from the records, the criterion used has been to consider only those cases in which less than two hours of rain occurred, with an average rate of rainfall greater than 1/20 inch per hour, and to omit thunderstorms and cases of snow, sleet, and hail. Thirty-five such cases have been found and give a total, per km^2, of $+13.47$ coulombs and -16.79 coulombs.

Certain instances have been found in which the charges on the rain have shown definite predominance of one or other sign; these are listed in Table 7, the rest of the 35 periods giving little resultant effect.

It will be seen that, in the majority of cases, there is a positive excess, the negative balance being due to the large negative excess on July 17. This is in contradiction to the general results of previous observers for showers, when a general negative excess has been reported.

TABLE 7—*Charges on rain with definite predominance of one or other sign*

Date	Time	Positive	Negative	Point-discharge	Av. rainfall	Ratio, sign of rain to sign of P-D
1939	*h m h m*	*coulombs /km²*	*coulombs /km²*		*in/hr*	
Feb. 12	13 10-13 15	0.07	0	....	0.10	....
Mar. 8	10 30-11 15	0.18	0	Negative	0.08	Negative
Mar. 24	15 00-15 30	1.29	0.12	Both	0.14	....
Mar. 25	00 15-01 00	0	1.06	Mainly positive	0.06	Negative
Apr. 17	14 15-14 20	0.41	0	Negative	0.40	Negative
Apr. 28	10 45	0.71	0	Negative	0.11	Negative
	13 45	0	1.39	Positive	0.13	Negative
May 6	03 00-05 00	0.68	0.05	Both	0.14	....
June 12	22 45-23 05	0.50	0.01	Mainly negative	0.07	Negative
June 28	16 15	0	0.43	Mainly positive	0.08	Negative
June 30	14 50	0.06	0.71	Mainly negative	0.35	Positive
July 15	15 30-16 00	2.09	0	Mainly positive	0.20	Positive
July 16	15 20	2.62	0	Both	0.20	....
July 17	13 00-13 45	1.61	10.89	Mainly negative	0.07	Positive
July 28	21 40	0.05	0	Negative	0.11	Negative
Aug. 2	08 35	0.02	0.68	Negative	0.25	Positive
Aug. 3	21 00-21 40	0	0.10	Negative	0.12	Positive

The ratio of the signs of rain-change and point-discharge shows a definite seasonal change at the end of June. This will be discussed later (see §21).

(13) *Thunderstorms*

Records are available during eight thunderstorms as shown in Table 8. Point-discharge during thunderstorms is erratic and changes sign often; it is therefore not included in Table 8.

TABLE 8—*Results during eight thunderstorms*

Date	Time	Positive	Negative
1939	*h m h m*	*coulombs /km²*	*coulombs /km²*
Apr. 17	12 00	1.64	0.05
May 7	17 00-18 00	0.03	0.54
June 30	11 00-13 00	6.72	9.41
July 5	14 00-15 00	0.30	0.01
July 9	15 00-17 00	56.73	0
July 17	11 00-12 00	0.69	0
Aug. 8	12 30-15 00	0.74	1.76
Aug. 21	04 00-06 00	0.30	0.21
Totals.................		67.15	11.98

This leaves a substantial positive balance which is more than accounted for by one day's records; had this single storm not been recorded, the total would have been negative.

(14) *Snow and sleet*

Measurements have been made during 14 periods of snow and sleet. The results show an almost even balance between positive and negative charge, giving +14.12 and −14.45 coulombs/km^2.

But it is noteworthy that, in a number of cases, there was an excess of one sign or the other, as shown in Table 9.

Table 9

Date	Time	Positive	Negative	Point-discharge	Notes
1938-39	*h m h m*	*coulombs /km²*	*coulombs /km²*		
Dec. 20	11 00-12 00	0.44	1.60	....	Showers
Dec. 21-22	Overnight	1.00	1.37	....	Showers
Dec. 30	23 00-24 00	1.66	0.21	....	....
Jan. 2	Various	1.18	6.36	....	Showers
Jan. 27	20 00-24 00	3.22	1.75	Both	Continuous
Mar. 26	00 00-08 00	0.61	0.46	Slight negative	Sleet-showers
Apr. 22	16 00-18 00	3.72	0.74	Mainly negative	Continuous

Here we see the fact that when the snow can be classified as "showers" it is more often negative, while when it is continuous, it is more often positive. The same division of snow-charges has been found in a re-examination of the results of Chalmers and Pasquill [1938].

(15) *Soft hail (Graupel)*

Four periods of soft hail have been recorded as shown in Table 10.

Table 10—*Results during four periods of soft hail*

Date	Time	Positive	Negative
1938-39	*h m h m*	*coulombs /km²*	*coulombs /km²*
Dec. 19	11 00-13 20	21.52	54.93
Dec. 20-21	Various	30.20	13.84
Jan. 4	14 00-17 00	0.48	0.90
Jan. 28	11 00	6.56	2.45
Totals.............		58.76	72.12

Some of the ten-minute periods are remarkable for the enormous average currents involved. The largest quantity was during the period $12^h 56^m$-$13^h 06^m$ on December 19, when the average current was -7.3×10^{-12} amp/cm^2. Other large average currents were (in units of 10^{-12} amp/cm^2): $+3.8$, $+1.1$, -0.8 (twice), $+0.7$, and -0.7. These have already been reported by Chalmers and Little [1939].

(16) *Fog*

Measurements were made during nine periods of fog, as shown in Table 11.

TABLE 11—*Results during nine periods of fog*

Date	Time	Positive	Negative	Notes
1938-39	*h m h m*	*coulombs /km²*	*coulombs /km²*	
Nov. 16	16 00-24 00	.017	.026	......
Dec. 15	07 00-20 00	.077	.091	
Jan. 14	11 00-14 00	.019	.007	....
Jan. 18	08 00-12 00	.029	.018	Drizzle
Jan. 19	08 00-16 00	.035	.070	Drizzle
Jan. 25	08 00-13 00	.031	.029	Snow
Feb. 2-3	Night	.058	.005	Slight rain
Apr. 3	20 00-23 00	.006	.020	....
May 29	04 00-08 00	.001	.140	....
Totals	....	.273	406	....

The resultant negative excess can be ascribed to the single period of May 29, but negative currents are noticeable in other cases, in agreement with the results of Scrase [1933].

(17) *Correlation between electrometer- and galvanometer-apparatus*

During May and June, when the electrometer-apparatus was under test, it was possible to compare the currents registered by this and by the galvanometer. As there is no connection between the two systems of collection of charge, this gives a valuable check on the functioning of both.

On nearly every occasion when the electrometer-apparatus showed a negative current, there was also a negative current shown by the galvanometer; there were more occasions of negative readings by the galvanometer-apparatus than by the electrometer-apparatus, but this can be accounted for by the effects of field-changes.

A detailed correlation over a period of 22 hours on June 5-6, shows that there is not complete agreement between the two measurements of current,

even for hourly averages, but there is a general tendency for simultaneous maxima and minima. The absence of complete correlation is probably due to the effect of field-changes in the galvanometer-apparatus.

In addition, the occasions of point-discharge agree with periods of very large positive and negative field as shown by the radioactive collector.

(18) *Comparison with single-drop measurements*

On three occasions, simultaneous measurements were made with the galvanometer-apparatus and with the single-drop apparatus as used by Chalmers and Pasquill [1938] with a collector a few meters away. The results are compared in Table 12.

TABLE 12—*Simultaneous results with galvanometer-apparatus and single-drop apparatus*

Date	Time	Single-drop	Galvanometer	Notes
1939	*h m h m*	*coulombs/km²*	*coulombs/km²*	
Jan. 11	12 45-12 55	+0.676	+0.960	Snow
	12 55-13 05	+0.378	+0.249	Snow
Jan. 28	11 16-11 26	+0.396	+0.384	Soft hail
	11 26-11 36	+0.077	+6.000	Soft hail
	11 36-11 46	−0.384	−1.830	Soft hail
	11 46-11 56	+0.684	−0.517	Soft hail
Feb. 28	10 16-10 26	+0.0316	−0.0166	Steady rain
	10 26-10 36	+0.0350	+0.0259	Steady rain
	10 36-10 46	+0.0067	−0.0063	Steady rain

The results with the snow show as good agreement as can be expected. The divergence in regard to soft hail and rain may be due to the field-changes, to the missing of some particles by the single-drop apparatus, or to secondary effects, such as splashing. In the case of the rain, it should be pointed out that the two negative currents happen to be two of the only three negatives over a period of $2\frac{1}{2}$ hours; also $3\frac{1}{2}$ minutes of single drops before $10^h\ 16^m$ showed a negative excess, while the galvanometer-reading for $10^h\ 06^m$–$10^h\ 16^m$ was positive. It is probable that the conditions for changes of sign are very local and so are not simultaneous at the two collectors.

(19) *Negative currents during May nights*

On a number of occasions during May, both measurements by the galvanometer and electrometer showed small but definite negative currents during the night, starting usually at some time between 20^h and 23^h and ending usually before 09^h. The field-measurements with the electrometer-apparatus also showed negative values, so that the conduction-current might well be responsible for the negative currents; estimates of the conduc-

tivity show it to have been of the same order as during the day time. Figure 3 shows an example. The number of similar instances during June was much less.

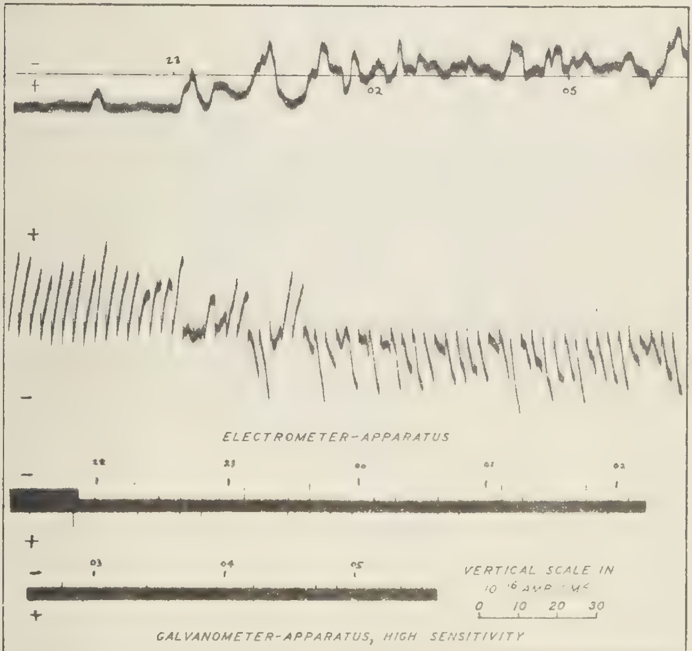

FIG. 3—NEGATIVE NIGHT FIELD AND CURRENT, MAY 10-11, 1939

The fact that the negative current was shown by two totally independent measurements is sufficient to rule out the possibility that there was any spurious effect.

A comparison with the "Daily weather report" showed that the occasions of negative current almost always coincided with reports of mist or slight mist from either or both of Tynemouth or Catterick, the two nearest reporting stations; usually, when there was no such report, the records showed the normal positive current and field. There seems to be little room for doubt that these negative currents must be associated with light mists. This is not quite the same phenomenon as reported by Scrase [1933] for fog, since Scrase found negative currents but positive fields, whereas here both are negative. It would seem that the mist must set up a negative field, in which the conduction-current is negative.

(20) *Phenomenon of May 10*

At $09^h\ 43^m$ on May 10, there was a record of a small positive point-discharge, lasting for less than one minute; the maximum current was 6.2×10^{-8} amp and the total discharge was 1.7×10^{-6} coulombs. The condenser of the galvanometer-apparatus was discharged at about the same time and showed a quantity corresponding to an average current of $+6.2 \times 10^{-16}$ amp/cm^2; the following ten-minute period showed an average current of -3.5×10^{-16} amp/cm^2. If the fields at $09^h\ 33^m$ and $09^h\ 53^m$ were the same and if the true air-earth currents during the two periods were the same, then there must have been apparent currents of $\pm 4.85 \times 10^{-16}$ amp/cm^2, caused by field-changes. Thus the field at the time of the discharge of the condenser would have been about 360 volts/meter greater than the normal. The average true current over the 20-minute period from $09^h\ 33^m$ to $09^h\ 53^m$ would be $+1.35 \times 10^{-16}$ amp/cm^2, if the fields were the same at the two times, and this can be compared with an average of $+2.0 \times 10^{-16}$ amp/cm^2 over the preceding hour.

At the same time, the electrometer-apparatus was functioning and this showed a sudden change of field at $09^h\ 43^m$, from its normal positive value to a large negative value, recovering fairly rapidly; the conduction-current record showed a corresponding period of negative current, which may be connected with the negative potential of the net. The records are shown on Figure 4.

It is difficult to find an explanation which can account for an apparent positive field with the galvanometer-apparatus and, simultaneously, an apparent negative field with the electrometer-apparatus. The most reasonable explanation that can be offered is that there was a sudden surge of negative charge to the "earth"-connections (a water-tap), perhaps from electrical apparatus in the building. As a consequence, the negative charge would be discharged through the point, giving an apparent positive point-discharge from the air. The collector of the galvanometer-apparatus was connected to Earth during this time and would receive a negative charge from Earth, so showing an apparent positive current from the collector; ten minutes later, this negative charge is discharged through the galvanometer. As regards the electrometer-apparatus, the fundamental fact would be the negative charge on the "earthed" guard-ring and surround; this would induce a positive charge on the net, and the corresponding negative charge would go to the electrometer, giving a negative reading. At the same time, the negative charge on the surround of the plate drives negative ions to the plate, giving the negative current shown. According to this explanation, the whole phenomenon was due to an accidental occurrence in the building and not due to any atmospheric effects.

(21) *Negative field on June 7*

During 06ʰ 30ᵐ to 09ʰ 00ᵐ on June 7, the galvanometer-apparatus showed mainly negative records and there was intermittent negative point-discharge. At the same time the electrometer-apparatus showed negative field, the maxima coinciding with the periods of point-discharge; there was also negative current with the electrometer-apparatus. Figure 5 shows the records.

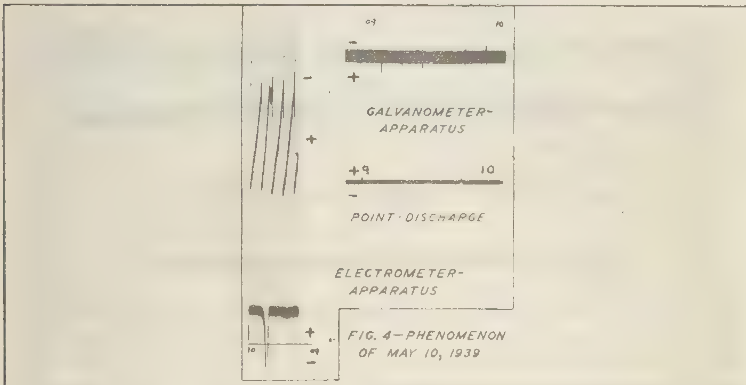

FIG. 4—PHENOMENON OF MAY 10, 1939

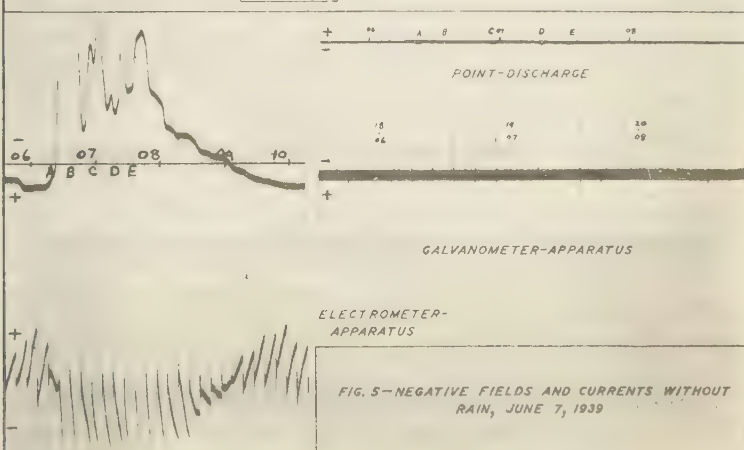

FIG. 5—NEGATIVE FIELDS AND CURRENTS WITHOUT RAIN, JUNE 7, 1939

During the time, a sharply defined cold front, moving south-southeast, passed over, associated with a vigorously developing depression over northern Scandinavia. The local conditions were a north wind bringing low cloud (Cu) but no rain. Neither Tynemouth nor Catterick reported any rain.

The negative field was approximately seven times the normal positive field, showing that there was considerable separation of charge within the cloud, in spite of the absence of precipitation. It therefore seems to be improbable that the separation could be effected by any process making use of rain or snow-particles as the agency of separation. This would eliminate the ion-capture process of Wilson [1929] and the breaking-drop process of Simpson [1909], but would not exclude the ice-friction process of Simpson and Scrase [1937].

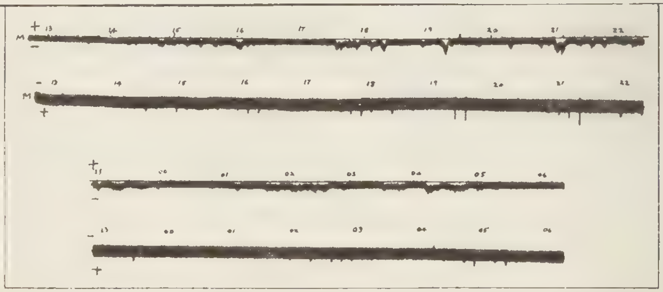

FIG. 6—POSITIVE RAIN-CURRENT AND NEGATIVE POINT-DISCHARGE IN CONTINUOUS RAIN, MARCH 27-28, 1939

VERTICAL SCALES:
CURRENT IN 10^{-16} AMP/CM^2 0 230.4 460.8
POINT-DISCHARGE IN MICROAMPS 0 5.20 10.40

FIG. 7—CURRENT AND FIELD OF SAME SIGN DURING RAIN, AUGUST 2-3, 1939

VERTICAL SCALES.
CURRENT IN 10^{-16} AMP/CM^2 0 [illegible] 20
POINT-DISCHARGE IN MICROAMPS 0 0.624 1.248

(22) *Relation between currents and point-discharge*

An examination of Tables 6 and 7 (continuous rain and showers) shows that, during the winter months, there is quite often a definite relation between the signs of the current and of the point-discharge, the signs being usually different. This has been discussed in detail for the record of March 27-28 [Chalmers and Little (1940)], which is reproduced in Figure 6; it is also very striking in the case of the two showers on April 28. The snow of April 22 is analyzed by ten-minute periods in Table 13.

TABLE 13—*Results for ten-minute intervals during snow of April 22*

Time	Current	Point-discharge
h m h m	*coulombs /km²*	*millicoulombs*
15 52-16 02	−0.026	−0.45
16 02-16 12	+0.018	0
16 12-16 22	0	0
16 22-16 32	+0.001	−0.11
16 32-16 41	−0.011	+0.11
16 41-16 51	+0.660	+0.11, −0.11
16 51-17 01	−0.041	0
17 01-17 11	−0.402	+0.56
17 11-17 21	+1.218	+0.11, −2.08
17 21-17 31	+0.432	−0.90
17 31-17 41	+0.360	+0.11, −0.33
17 41-17 51	−0.062	−0.11
17 51-18 01	−0.024	+0.22
18 01-18 11	−0.117	−0.11
18 11-18 21	+1.032	+0.11, −0.56
18 21-18 31	−0.020	−0.11

It will be seen that, not only are the two currents opposite in sign in the majority of cases, but that the greatest precipitation-currents are associated with the greatest point-discharge currents.

In the summer, however, matters are different, as is strikingly shown by the rain of August 2-3, of which the record is reproduced in Figure 7. For 14 hours of continuous rain, the signs of the current and point-discharge are shown in Table 14 in the numbers of 10-minute periods.

Further, it may be noted that the single period of positive point-discharge ($05^h\ 15^m$–$05^h\ 25^m$) coincided with a large positive current; and the periods of negative point-discharge were usually the periods of greatest negative current. The currents were up to 40 times the fine-weather current and, unless the conductivity was considerably greater than normal, it is unlikely that the effects could be accounted for by conduction-currents, nor can field-changes be responsible.

TABLE 14—*Results during 14 hours of continuous rain, August 2-3, 1939*

Current	Point-discharge		
	Positive	Negative	Zero
Positive	1	1	13
Negative	0	21	43
Zero	0	0	4

(23) *The origin of rain-charges*

It is not easy to give a satisfactory complete account of the various phenomena found in these and similar measurements.

It appears probable that in most clouds, and not only in thunder-clouds, there is a separation of charge with an upper positive and lower negative charge, as is shown by the predominance of the negative point-discharge currents. Simpson and Scrase [1937] have suggested that ice-friction may be the process responsible.

The charges on falling rain and snow-particles may originate in the cloud or may arise during the fall, or perhaps both processes operate. If there are two processes giving rise to opposite signs of charge, this might well account for the difference between the effects in summer and winter, and also for the temporary, and perhaps local, changes of sign of the precipitation-current. As a tentative theory the following is put forward: The falling ice-particles in a cloud acquire a negative charge from the process of ice-friction, but below the cloud they acquire positive charge by ion-capture, as suggested by Wilson [1929]. If circumstances are such that ion-capture is likely to be considerable, then the particles will arrive at the Earth with positive charges, but if there is little ion-capture, they will retain their original negative charges. Chalmers [1947] has recently shown that ice-particles should be more efficient in ion-capture than water-drops, so that we should expect the ion-capture process, giving positive precipitation, should occur more frequently in winter than in summer, and this is found for continuous rain (see Table 6). In the case of thunderstorms, there are additional factors, including the region of positive charge in the base of the cloud and the destruction of charges by lightning-flashes.

In the case of mist and fog, the setting up of a negative field must be due to some process other than ice-friction, since this cannot operate under conditions such as those of the May nights discussed in §18. Also, the breaking of drops, suggested by Simpson [1909] could not be responsible. Therefore some other process of separation of charge must be postulated for mists, and it is reasonable to suppose that the same process might operate in clouds. There are no good grounds for suggesting the nature of such a process.

(24) *Transfer of charge to the Earth*

By conduction and precipitation, the measurements have shown a balance of +72 coulombs/km^2 over the period of measurement. To account for the missing and faulty records, and the two extra months of the year, it can be estimated that the total might be about +100 coulombs, but, since the greater part of the 72 coulombs is confined to a few days, no very great reliance can be placed on this result.

Assuming the separation of points to be similar to that at Kew, point-discharge would give, for a full year, about −90 coulombs (see §9).

The estimate of the charge carried to the Earth by lightning-flashes is made more accurate than was possible for Wormell [1930] by the results of Golde [1945] who found evidence for the number of flashes to Earth per square mile per year to be about six for England and Wales. As Durham is in an area whose number of thunderstorms is less than that for the average of England and Wales, we can take the number of flashes to be under five, and this gives rather less than two flashes per km^2; accepting Wormell's [1939] estimate of 20 coulombs per flash, we get about −35 coulombs, if all the flashes bring down negative charge.

The conclusion to be drawn is the same as that of Wormell, that the balance of current to the Earth is probably somewhat negative for a site in England. In tropical countries, the effects of lightning and of point-discharge would probably be greater; but over the sea, these would be much less, and probably it would be found that the total balance over the whole Earth would be zero, thus agreeing with the idea that the four processes discussed are responsible for the whole of the transfer of charge between the Earth and the atmosphere.

(25) *Conclusion*

Measurements have been made with samples of various types of weather, so that many of the conclusions are based on sufficient samples, but the totals must be accepted with reserve, owing to the missing and faulty records. It is hoped to continue the work, to be able to produce reliable data over a period. It will be necessary to measure the conduction- and precipitation-currents separately, in order to avoid the difficulty of the change of sensitivity required. Measurements of the field, when this is too small for point-discharge, and measurements of the rate of rainfall are also desirable.

The authors wish to thank the Curators of the Durham University Observatory for the use of the "electrometer-apparatus".

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Durham Colleges in the University of Durham,
Durham, England, March 14, 1947

HENRY FAWSIT SKEY, 1877–1947

By H. F. Baird

On January 16, 1947, at his home in Christchurch, New Zealand, Henry Fawsit Skey, a former Director of the Christchurch Magnetic Observatory, died suddenly from a heart attack which overcame him just before noon whilst he was having a cup of tea with his wife.

He was born in April, 1877, at Dunedin, New Zealand, where he attended the Otago Boys' High School, and later the Otago University. There he gained a senior scholarship, and next year graduated with honors in Physics.

Harry Fawsit Skey
1877-1947

His association with the Magnetic Survey of New Zealand began soon after, in May, 1899, when he joined C. Coleridge Farr as Assistant at Dunedin where field-observations were then in progress. He remained with the Magnetic Survey throughout his professional career which ended with his retirement in May, 1940. In the early months of this career working and traveling conditions in the field were too much for his physique, and he suffered a breakdown in health from which, as he confided a few months before he died, he never completely recovered. However, it was symptomatic of his tenacity of purpose that he carried on efficiently in succeeding years with great industry and enthusiasm, even though in many of these years he was almost without assistance.

Soon after he joined the Magnetic Survey, the Magnetic Observatory

was built at Christchurch, and Mr. Skey took a large share of the work required there in installing magnetographs, seismographs, and atmospheric-electric equipment. Shortly after this installation the city of Christchurch put down an electric tram-system which gradually built up to such disturbance that in 1912 Eschenhagen magnetographs were obtained for temporary installation by him at Amberly, some 30 miles away, and these instruments have remained there ever since. There, too, he later shifted the Adie magnetographs from Christchurch, to operate in the same cellar with the la Cour set which was used during the last Polar-Year program.

Mr Skey had a good understanding of fine mechanisms, and derived much pleasure in his own workshop from making innovations to observatory-equipment. He was a great believer in the principle that many geomagnetic phenomena occurred in regular cycles which obscured one another by overlapping and he spent much time searching for various periodicities, a task which greatly interested him.

Probably Mr. Skey's greatest prowess was in the technique of making magnetic observations, for which he had an ideal temperament. He did almost all of the actual observations in the original magnetic survey of New Zealand, but in January, 1904, C. Coleridge Farr, who had by then gained a doctorate in science, left the Observatory for a university post, and Mr. Skey necessarily had to restrict his field-activities when he succeeded Dr. Farr at the Observatory. However, in the first ten years of his service he observed over most of the mainland of New Zealand and some of its outlying islands, including the Chatham Islands, which he revisited in 1924 in his only return to magnetic field-observation duties.

From his father he inherited a great liking for astronomy, and in 1924 did precise latitude and longitude observations to fix the position of the Chatham Islands. He also did much to foster interest in astronomy at many schools in New Zealand. As a seismologist he visited many areas which had been disturbed by large earthquakes. In New Zealand he had charge of the first program of extensive observations of upper-air currents by means of pilot-balloons.

His was a very kindly nature indeed, and he was greatly respected for his justice and wisdom. He was a great lover of animal pets and beautiful flowers, and it was a great joy to him that the Observatory was set amongst the beauty of the Christchurch Botanic Gardens. Impaired health early prevented an active interest in sport, but from his workshop and his books he derived great pleasure. He published a few scientific papers, and took a very large share in preparing for publication the results in "A Magnetic Survey of the Dominion of New Zealand", by C. C. Farr.

Mr. Skey is survived by his widow and two daughters.

Magnetic Observatory,
Botanic Gardens, Christchurch, New Zealand, April 8, 1947

LETTERS TO EDITOR

(See also pages 174, 188, 216, and 232)

SOME EARLY SIGNAL-INTENSITY MEASUREMENTS

Eighteen years ago the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, collected radio wave-propagation data throughout the world during Cruise VII of the research Yacht *Carnegie*. In 1930 the log-books of the yacht were examined for high-frequency radio-propagation data which were abstracted and summarized.

One of the studies undertaken by means of these data was a collection of radio signal-strengths over long distances in terms of local time at the midpoint of the path of propagation. The reasoning which led to the reference-time of this path's midpoint was prompted by the fact that the signal-strength data were collected on a moving observatory. Since the yacht cruised in all oceans and made measurements of signals arriving from all directions, it appeared natural to choose a time-scale upon which it was possible to represent the information in such a way that any portion of it could be compared with any other part. There resulted a graph of Figure 1.

With the strong position now occupied by predictions of radio propagation, based as they are upon hundreds of thousands of observations taken over many years, it is interesting to look back upon one of the first attempts at a world-wide prediction of radio transmission-conditions for average areas in temperate and tropical latitudes.

Upon examination of Figure 1 in light of present knowledge of the ionosphere it is clear that the zero-signal portion in the lower center is related to daytime absorption in the *D*-layer, embracing the standard broadcast-band and the medium high-frequency range. Large-amplitude signals at night over the 6 to 9 Mc/sec region obviously correspond to nighttime *F*-layer propagation at extreme distances.

The transition in shape of the contours in the vicinity of 18 Mc/sec can well be interpreted as related to change from *E*-layer to *F*1-layer mode of propagation in the daytime. At around 27 Mc/sec the skew-symmetry associated with daytime *F*2-layer propagation begins. Zero-signal zones at night above 32 Mc/sec are undoubtedly caused by limitation of electron-concentration to values too low to support propagation at these frequencies.

It is interesting to note the distinct shift of maximum signal-contours to middle afternoon at the highest frequencies in agreement with time of maximum *F*2-layer electron-densities in the tropics.

The basic data upon which the graph depends were gathered between May, 1928, and November, 1929, over tropical and temperate latitude

signal-paths and were reduced to standard transmitter power except at the higher frequencies. Such an adjustment for the higher frequencies was not possible because most of the observed signals in this part of the spectrum originated as harmonic radiations from transmitters operating at lower frequencies. The epoch during which these observations were made corresponds roughly to the present epoch, in so far as sunspot-numbers are concerned.

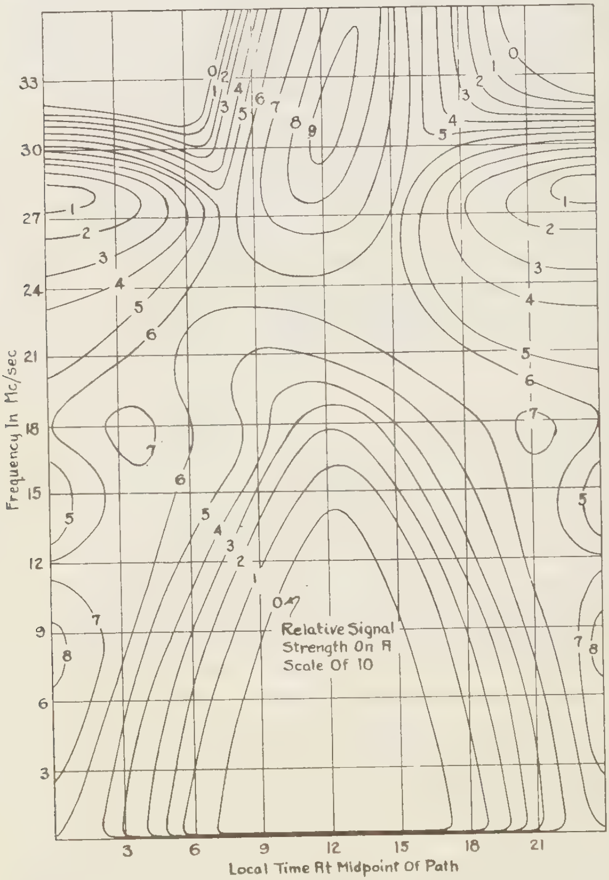

FIG. 1—WORLD-WIDE SIGNAL-INTENSITY CONTOURS FROM MEASUREMENTS MADE ON YACHT CARNEGIE DURING CRUISE VII, MAY, 1928–NOVEMBER, 1929

One of the observations contained in the data may be of historical interest, that is, in October, 1929, two-way contact was maintained between the *Carnegie* at Honolulu, Territory of Hawaii, and the Naval Research

Laboratory at Washington, D.C., in full daylight on 18 and 20 Mc/sec, respectively. This was believed at the time to be the first contact during daylight between Honolulu and Washington on high radio-frequencies.

The author is indebted to the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for basic data presented.

Little Silver, New Jersey, February 23, 1947 S. L. Seaton

FIVE INTERNATIONAL QUIET AND DISTURBED DAYS FOR JULY TO DECEMBER, 1946

Reports of geomagnetic activity for the last six months of 1946 have been received from a sufficient number of magnetic observatories so that the international quiet and disturbed days can be selected in accordance with the method outlined on pages 219-227 in the December, 1943, issue of this Journal. The selection is based on the reports of magnetic character on a scale of 0, 1, and 2 from an average of 34 observatories and of K-indices from an average of 27 observatories.

Month	Quiet					Disturbed				
1946										
July	1	4	5	13	20	7	18	26	27	29
August	21	22	23	26	29	7	11	14	15	31
September	1	6	15	25	26	18	19	22	23	28
October	8	13	17	18	30	9	20	26	27	31
November	14	27	28	29	30	1	6	21	24	25
December	9	14	15	20	30	5	10	11	12	19

Department of Terrestrial Magnetism, W. E. Scott
Carnegie Institution of Washington,
Washington 15, D. C., May 20, 1947

ECLIPSE EXPEDITION TO STUDY IONOSPHERE

What happens to the nebulous ionosphere, the all-important radio-reflecting layer high above the Earth, when the Moon's shadow "punches a hole" in it during an eclipse of the Sun? This will be investigated on May 20, 1947, by the Army Air Forces-National Geographic Society Eclipse Expedition at Bocayuva, Brazil. Because the ionosphere is created by ultraviolet radiation from the Sun, which makes air-molecules in the upper atmosphere electrically conducting, scientists are interested in knowing what happens to the ionosphere when this radiation is cut off suddenly during an eclipse.

Study of the ionosphere is important because of the increasing use of long-distance communication by radio. High-frequency radio signals travel around the Earth in a series of giant bounces between the ground and the reflecting layers of the ionosphere, which range from about 50 to 250 miles in altitude. When these layers disappear or are disrupted, long-distance communication by radio fails or is garbled.

Operates on principle of radar—During the eclipse of May 20, 1947, what happens to the ionosphere will be determined by probing upward with a continuous series of multifrequency radio impulses, operating on the same principle as radar impulses which echo back from a target. Traveling with the speed of light, these signals normally are reflected back to the ground by the ionosphere, but during the eclipse the signals either will not be reflected back or will reveal changes in the condition of the ionosphere's E-, $F1$-, and $F2$-layers.

The Moon's shadow, striking obliquely down upon the Earth, will first cut out the E-layer over the site of the eclipse observation, then the $F1$, and finally the $F2$, although this layer probably will not be completely cut out. From the behavior of the radio echo, it will be possible to determine what happens to each layer in turn as the sun's radiation is shut off from it.

Sun's corona studied—The observations will help determine whether the ionosphere is produced entirely by radiation of ultraviolet light from the Sun or whether it is created in part by ultraviolet light from the Sun's corona, the vast, nebulous envelope of gas that extends out in space around the Sun. The corona is known to emit some ultraviolet light. Just before the eclipse, the Moon will shut off part of the corona before it covers the Sun itself. Again, after the Moon passes beyond the Sun, it will once more cover part of the corona. If the radio signals reflected while the corona is covered show any reaction in the ionosphere, this will be evidence that the ionosphere is created in part by the corona's ultraviolet light.

It is hoped to get more information on the time required for the fragments of the molecules of air in the ionosphere that are disrupted by radiations from the Sun to recombine or spring back together when the Sun's light is cut off. This will help to indicate how long the various layers persist after the Sun's light is cut off at night.

Compare normal behavior—When light from the Sun is shut off, the already disrupted molecules recombine, but no more disruption takes place, so that the ionospheric layers cease to be electrically conducting until sunlight again falls upon them. The disrupted molecules recombine much more slowly at high altitudes where the air is very rarefied, than lower down where the molecules are close together. Small, rapid fluctuations in the ionospheric height and density will also be looked for. All such information will be useful in better understanding the ionosphere, which in turn will help toward improving transmission of radio over long distances.

Observations of the ionosphere will be made for many days before and after the eclipse so that its normal behavior can be compared with what happens during the eclipse. The radio transmitter sending out the pulses makes a continuous automatic record on motion-picture film. It covers a range of 1 to 20 Mc/sec, the range of frequencies used in long-distance communication by radio. It will be operated by James M. Watts and Franklin Kral of the National Bureau of Standards.

National Geographic Society,
Washington 6, D. C., April 3, 1947

GILBERT GROSVENOR,
President

Note: Dr. Lelio Gama of Observatorio Nacional, Rio de Janeiro, Brazil, writes under date of April 26, 1947:

"We are planning to carry out a special program for magnetic observations during the coming eclipse of the Sun on May 20, 1947. The observations will be taken at our magnetic station in Vassouras, a small village about four hours' traveling by train from Rio. In order to make preliminary arrangements and the testing of a new magnetograph, I had to leave for Vassouras in January, and I stayed there much longer than I expected. Concerning these magnetic observations, I will do my best to secure trustworthy material for subsequent investigation of the possible effect of the eclipse upon the Earth's magnetism. From what I have examined into this matter, however, I am under the impression that searching for effects of the eclipse upon the Earth's magnetic field is somewhat like looking for a needle in a haystack."

REVISED FORM OF SOLAR AND MAGNETIC DATA FROM MOUNT WILSON OBSERVATORY

Mrs. Mulders, who for many years has been estimating the solar character-figures from K_2 and $H\alpha$ spectroheliograms, is leaving the Observatory this month. She is moving to San Francisco where her husband has accepted a position with the United States Navy.

It seems to me that this is a good time to terminate the publication [in Terr. Mag. since 1930] of these character-figures, which have not proved very useful* and whose publication at Zurich was terminated some years ago. Since several magnetic observatories estimate the magnetic character-figure and since other more quantitative measures are superseding it, I question the advisability of continuing its publication also. It is probably worth while to continue the table of magnetic storms and the remarks about the solar activity contemporary with them.

*The data already published, it is thought, will prove more useful than Dr. Nicholson believes when they and other data are more fully analyzed.—*Ed.*

I believe that investigations along other lines in this field will pay better dividends. We have several in mind which will need the time formerly devoted to the preparation of character-figures.

Carnegie Institution of Washington, Seth B. Nicholson
Mount Wilson Observatory,
Pasadena 4, California, February 14, 1947

SOLAR AND MAGNETIC DATA, JANUARY TO MARCH, 1947, MOUNT WILSON OBSERVATORY

An immense complex bipolar sunspot group, Mount Wilson No. 8438, crossed the solar disk from March 3 to 16. It was the second largest spot group ever recorded, having been surpassed in size only by the great group of February 1946. Group 8438 was a return or at least an outgrowth of a large group, No. 8392, which crossed the solar disk from February 5 to 18.

No great magnetic storm was associated with either of these groups, although the largest magnetic storm of this quarter, March 2-5, began when the great spot was just coming around the east limb of the Sun. No intense flares were observed at Mount Wilson from January to March although intense flares usually occur in groups of this size.

Table 1—*Magnetic Storms*

Greenwich civil time						Range in H
Beginning			Ending			
1947	h	m	d	h	m	γ
Jan. 4	11	17*	05	11	..	75
Jan. 16	03	30*	17	03	..	140
Jan. 24	06	21	26	14	..	135
Feb. 16	03	00	17	18	..	170
Mar. 2	04	02	05	02	..	330
Mar. 7	05	37	09	13	..	190
Mar. 12	05	..	17	12	..	165
Mar. 27	07	28	29	01	..	150

*Sudden commencement.

Carnegie Institution of Washington, Seth B. Nicholson
Mount Wilson Observatory,
Pasadena 4, California, May 17, 1947

NEEDS OF GEOPHYSICAL SERVICE IN AUSTRIA

As leader of the Geophysical Service in Austria, I now take the opportunity to enter into communication with colleagues in countries which have not been devastated by the war. I turn to you with the request for your assistance in scientific connections, and, if possible, I add the request for support of my coworkers in a material sense.

As a direct result of the war the Geophysical Service here has been especially hard hit in its installations. It has suffered the loss of almost all of its difficultly replaceable special equipment. The magnetic base-station was completely destroyed. We also lack all the recent scientific literature.

My first request, is therefore that at least the most important publications in our common fields of geophysics be sent us. Further I am striving to reestablish the Magnetic Observatory. In this connection, I seek advice as to the suitable instruments and firms and other sources from which we could procure the lacking apparatus.

Moreover, I request also help and support in the material field. We stand, after overcoming a hunger period of more than a year's duration, at the beginning of an unusually early winter. There is only a little fuel and insufficient food. Our personal resources and our own capacity for resistance against the many deprivations are in large measure exhausted. We have until today kept silent in the hope of an improvement in our condition in a reasonable time. In view of the present conditions, however, I hold further silence as false. We are not asking for alms, but are prepared to reimburse those who help us, after the return of normal conditions for their outlays with greatest thanks. Especially would we be served by the sending of certain highly important foodstuffs (fat and whites of eggs). At present, here in the Geophysical Service, five persons are employed of whom two are women.

Geophysical Service of Austria,
Hohe Warte 38, Vienna XIX,
Austria, November 13, 1946

M. Toperczer,
Director

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

January to March, 1947

(*Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h 01^m.3 W. of Gr.*)

January 2-6—An extended period of moderately disturbed conditions was recorded during the first few days of January. The disturbance began gradually at about 08^h 30^m GMT, January 2, and continued until about 16^h 00^m, January 6. Activity consisted chiefly of variations of rather large amplitude and long period forming small bays throughout the storm. One K-index of 6 was recorded near the beginning of the disturbance and four K-indices of 5 were recorded just before the end.

January 24-27—A rather severe magnetic storm began abruptly at 06^h 51^m GMT, January 24. For the first twenty-two hours, or until 05^h, January 25, activity was slight. However, after 05^h there was a marked increase in storminess when oscillations of short period and large amplitude began to occur and continued until about 19^h, January 25. During this period three K-indices of 7 and one of 8 were recorded. After 19^h, however, activity began to decrease and the character of the storm changed to fairly long-period oscillations superposed on very large bays. The highest K-index recorded during this portion of the storm was 6, which came during 12^h-15^h, January 26. The storm gradually died out at about 03^h, January 27. All magnetograms for the remainder of January showed signs of lesser disturbances. The storm was accompanied by a very bright auroral display.

February 8-10—A moderately disturbed period began gradually at about 08^h GMT, February 8, and continued until 17^h, February 10. The disturbance consisted chiefly of short-period oscillations superposed on bays of various sizes. Two K-indices of 6 were recorded during 09^h-15^h, February 8.

February 16-19—A moderate magnetic storm began rather abruptly at 03^h GMT, February 16. The first five hours produced little activity; however, at about 08^h 15^m, February 16, rather severe changes began to occur. During the following eight hours the storm reached a maximum of disturbance when three K-indices of 8 were recorded. This activity consisted of short-period, large-amplitude oscillations and continued until 17^h, February 16, at which time the character of the activity changed to short-period oscillations of small amplitude. During most of this latter activity all elements were recording at fairly normal values and until about 06^h, February 18 this condition existed. The storm began to show signs of dying out

after 06^h, February 18; however, all activity did not disappear until 06^h, February 20.

March 2-5—A major magnetic storm began at 04^h GMT, March 2. For the first three hours there was very little activity but at 07^h rather sudden changes began to occur. During the following nine hours the activity consisted of short-period, large-amplitude oscillations superposed on very large bays. At about 03^h, March 3, the storm subsided and almost died out; however, at 06^h 30^m renewed activity began. At 08^h, March 4, the most severe activity of the storm began and during the following two hours horizontal intensity decreased about 1715 gammas, while vertical intensity decreased about 1061 gammas. Between 09^h and 10^h, declination went through an over-all change of about 7½°, first decreasing about 3°, then increasing 4½°. At about 10^h 15^m, March 4, the storm subsided and at about 12^h, March 5, the ending occurred. *K*-indices of 9 were recorded during 06^h-09^h and 09^h-12^h, March 3, and between 06^h-09^h, March 4.

March 7-10—A second major magnetic storm of March may be said to have had its beginning at 05^h 37^m GMT, March 7. Actually the disturbance was a continuation of the storm of March 2-5. During the first two hours of the storm there was very little activity; however, at about 07^h 30^m large bays began to form. There was, as yet, no sign of short-period activity but at 15^h, when all elements had returned approximately to their normal recording position, the short-period, low-amplitude oscillations began to occur. This sort of disturbance continued until about 03^h, March 8, and at this point the storm almost died out. At 06^h, March 8, there was renewed activity and at 08^h 15^m very large changes in all elements began to take place; it was from this time until 17^h, March 8, that the storm reached a maximum of disturbance. *K*-indices of 7, 9, and 8 were recorded for this period. After 17^h activity subsided but there was continued storminess, the character of which consisted chiefly of short-period, low-amplitude oscillations superposed on large bays. Except for a short period between 08^h 45^m and 09^h 15^m, March 9, when there occurred short-period oscillations of large amplitude resulting in *K*-indices of 8 and 7, the storm then continued to gradually die out. The ending may be said to have been at 08^h, March 10; however, occasional disturbances were recorded for several days afterwards. A very brilliant auroral display accompanied this storm.

March 14-17—A third magnetic storm of the month may be said to have had its beginning at 08^h GMT, March 14; however, it is undoubtedly a continuation of the disturbance which began during the early part of the month. The storm here described began rather gradually from an already disturbed period and the first ten hours of its activity consisted mainly of large, irregular bays. At about 18^h of the same date almost all activity ceased and for the next thirteen hours, or until 07^h, March 15, there was little disturbance; 07^h, March 15, marked the renewal of activity and by

the end of that hour very large and quick changes began to occur. Between $07^h\ 50^m$ and $09^h\ 15^m$, vertical intensity decreased 720 gammas and between $07^h\ 55^m$ and $10^h\ 06^m$, horizontal intensity decreased almost 1600 gammas, then recovering during the following two hours. At $10^h\ 08^m$, declination suddenly increased about 5½° but recovered almost immediately. Severely disturbed conditions continued until about 17^h, March 15. K-indices of 8, 9, 9, and 8 were recorded between 06^h and 18^h on this date. After 18^h the storm subsided to a great extent and by 00^h, March 16, all elements were practically undisturbed. Moderate disturbances began to reappear at about 15^h, March 16, and continued until the storm finally died out at about 14^h, March 17. Minor disturbances continued to show up for several days.

March 22-24—A moderately disturbed period began rather gradually at about 03^h GMT, March 22. It was of short duration, ending at about 16^h on the same date. However, there was a reoccurrence at about 08^h, March 23, which continued until about 11^h, March 24. The maximum of disturbance for the period was reached during 15^h-18^h, March 23, when a K-index of 7 was recorded.

March 26-31—Magnetic conditions again became disturbed at about 00^h GMT, March 26, and continued until about 20^h of the same date. For the next 8½ hours there was little or no disturbance but at $04^h\ 30^m$, March 27, there was renewed activity which continued until 24^h, March 31. The most disturbed portion of the period was during 06^h-12^h, March 27 (K-indices of 7 and 8) and 03^h-18^h, March 28 (K-indices of 7, 7, 7, 7, and 6).

Joel B. Campbell, *Observer-in-Charge*

Witteveen Magnetic Observatory

January to March, 1947

(*Latitude 52° 48′.8 N., longitude 6° 40′.1 or $0^h\ 26^m.7$ E. of Gr.*)

January 2—A minor disturbance occurred between 15^h and 21^h GMT, resulting in one K-index of 5.

January 3—During a minor disturbance between 15^h and 24^h GMT, one K-index of 5 was recorded.

January 4-6—A period of disturbed conditions began with a sudden commencement at $11^h\ 16^m$ GMT, January 4. Two K-indices of 5 were noted for the six hours between 15^h and 21^h, January 5; apart from this there was only slight disturbance until 23^h, January 6.

January 14-17—After the solarflare-effects on January 14 (from $09^h\ 49^m$ GMT, till $10^h\ 04^m$, accompanied by radio fade-out) and on January 15 (from $10^h\ 48^m$ till $10^h\ 58^m$) there was a sudden commencement at $03^h\ 29^m$, January 16. The disturbance that followed was slight in general and lasted

until about 14^h, January 17; only two K-indices of 5 were recorded between 03^h and 06^h and between 18^h and 21^h, both on January 16. Aurora borealis was observed from 18^h 35^m till about 22^h, January 16.

January 24-28—This period of magnetic activity with only temporarily moderate disturbance commenced suddenly at 06^h 20^m GMT, January 24, and lasted until about 03^h, January 28. At 23^h 50^m, January 24, activity abruptly revived; at about 04^h, January 25, aurora borealis was observed, while in that time-interval a K-index of 5 was noted. Apart from this only one K-index of 6 and three K-indices of 5 occurred in the whole period which ended at 03^h, January 28.

February 7-10—This period of generally slight magnetic activity suddenly began at 08^h 13^m GMT, February 7. From about 08^h, February 8, activity slowly increased to a moderate disturbance which lasted from 17^h, February 8, till about 05^h, February 9. After 20^h, February 9, especially D was temporarily moderately disturbed.

February 14—After 21^h GMT, aurora borealis was observed while magnetic conditions were scarcely disturbed.

February 16-17—After a sudden commencement at 02^h 59^m GMT, February 16, magnetic activity slowly increased to moderately disturbed conditions. Between 09^h, February 16, and 06^h, February 17, two K-indices of 6 and five K-indices of 5 were noted. Aurora borealis was observed between 18^h 45^m, February 16, and 01^h, February 17.

February 19—A minor disturbance lasted from about 14^h GMT, February 19 till about 04^h, February 20. Only one K-index of 5 occurred.

March 2-4—After a Dellinger-effect at about 12^h 35^m GMT, February 28, a period lasting nearly three days of strongly disturbed conditions commenced at 04^h 01^m, March 2. At 08^h 17^m, March 2, strong activity began suddenly and lasted for about two hours. The disturbance was in general moderate, until 18^h, March 3, when it developed into a mild storm lasting till about 04^h, March 4; during this time-interval two K-indices of 7 and two K-indices of 6 occurred. Ranges were: D, 64′; H, 540 gammas; Z, 265 gammas. After that the disturbance decreased rapidly; with exception of the interval 18^h–21^h, March 4, when a K-index of 6 was noted, the conditions were only slightly disturbed after 11^h, March 4. Aurora borealis was observed at about 19^h, March 2, and from 01^h 00^m till 02^h 15^m, March 3. In the evening of March 3 and the following night fog and moonlight prevented observation.

March 7-9—This period of magnetic activity commenced suddenly at 05^h 35^m GMT, March 7. During the first twenty-seven hours the disturbance was only slight. After 09^h, March 8, it increased gradually, so that about 15^h already a K-index of 7 was noted. A K-index of 7 was noted again for the last three hours of March 8; three further intervals had a K-index of 6. After 02^h, March 9, the disturbance decreased rapidly and

ended about 13^h. Ranges: D, 68′; H, 425 gammas; Z, 225 gammas.

March 22-24—A period of minor disturbance began about 03^h GMT, March 22, and lasted till about 08^h, March 24. Only two K-indices of 5 were noted.

March 27-28—After a sudden commencement at 04^h 27^m GMT, March 27, there was moderate activity on March 28 when five K-indices of 5 occurred.

March 29-31—Slight activity occurred between 19^h GMT, March 29, and 16^h, March 31. A K-index of 5 was noted for the first two hours of this period.

H. P. Th. van Lohuixen, *Leader*

Cheltenham Magnetic Observatory

January to March, 1947

(*Latitude 38° 44′.0 N., longitude 76° 50′.5 or 5^h 07^m.4 W. of Gr.*)

January 25-26—Following a day of slight disturbance, a storm of moderate intensity began at about 03^h GMT, January 25, the major part of the disturbance occurring between 03^h and 16^h, January 25, and consisting of long-period, irregular oscillations of moderate amplitude in all three elements. The perturbations continued on a diminished scale subsiding at about 15^h, January 26. Minimum H was 18,072 gammas at 15^h 11^m, January 25. On January 25 the K-sum was 36, three fives and one six being scaled.

February 16-17—This moderate disturbance was ushered in by a sudden commencement in H at 02^h 59^m GMT, February 16. Following a momentary 2-gamma decrease in H there was an increase of 37 gammas. H showed small oscillations till 09^h. From 09^h to 24^h, short-period oscillations, superimposed on irregular long-period oscillations, predominated. Short-period oscillations were particularly marked in D and Z from 12^h to 21^h. There was a recrudescence in activity at about 00^h, February 17, showing irregular, long-period oscillations which continued until the return to normal conditions at about 10^h. There were peaks in all three elements in the first hour of February 17. K-indices of 6 occurred in the fourth three-hour period of February 16 and in the first and second three-hour periods of February 17. Ranges: D, 51′; H, 169 gammas; Z, 153 gammas.

March 2-4—A severe magnetic storm began with a sudden commencement in both D and H at 04^h 01^m GMT, March 2. After four hours of only slight disturbance, a second abrupt departure took place in all three elements at 08^h 17^m, H suddenly increasing 103 gammas in about two minutes. H exhibited short-period oscillations of moderate and small amplitude until about 20^h, March 2, when longer-period motion set in. At about

11^h, March 3, rapid pulsations again took place until 18^h 23^m, when H suddenly began to increase. The increase accelerated and culminated in a prominent peak at 20^h 43^m, H having increased 403 gammas. H then decreased showing long-period oscillations. Following a rather sharp depression during the ninth hour, March 4, H resumed normal values although rapid pulsations continued for another half day.

The character of the D-disturbance rather closely paralleled that of the H, long-period motion following short-period pulsations on two occasions. Throughout the storm the D-trace was irregular. A depression in D, representing a near-easterly extreme occurred at 20^h 45^m, March 3, at the time of the large H-peak. The easterly extreme took place at 01^h 55^m, March 4, and the westerly extreme at 10^h 33^m, March 3. A well-developed peak, representing a high westerly value, occurred at 08^h 28^m, March 4, at the time of the depression in H.

The Z-trace was rather badly disturbed throughout. For two twenty-four hour periods the general character of the Z-trace was similar. From about 17^h, March 2, to 01^h, March 3, Z increased gradually and then decreased until near 10^h, March 3. Z then increased gradually until the twenty-first hour and then steadily decreased until near 09^h, March 4. The depressions in Z during the tenth hour, March 3, and the ninth hour, March 4, concurred with depressions in H. Minimum Z-value occurred at 09^h 52^m, March 3, and maximum Z at 20^h 43^m, March 3, at the time of the prominent peak in H.

Nine K-indices of 6, three of 7, and one of 8 were scaled. The K-sum for March 3, was 49. Minimum H of 17,966 gammas was at 08^h 26^m, March 4. Ranges: D, 1° 00′; H, 483 gammas; Z, 530 gammas.

March 7-9—A moderate magnetic storm began with a sudden commencement in both D and H at 05^h 36^m GMT, March 7, at which time H suddenly increased 16 gammas. The activity was slight until about 08^h, March 8, when long-period, irregular oscillations set in to be followed about four hours later by rapid pulsations in all three elements. The perturbations resumed their irregular, long-period character after seven or eight hours and disturbances of moderate amplitude lasted until about 13^h, March 9.

Between 09^h and 10^h, March 8, H began to decrease and reached its minimum value for the storm at 14^h 56^m of 18,005 gammas. D and Z were rather uniformly disturbed throughout. Three K-indices of 6 were recorded. Ranges: D, 36′; H, 282 gammas; Z, 220 gammas.

March 15—A short-lived storm began at about 08^h GMT, March 15, although an abrupt departure occurred shortly afterwards at 08^h 42^m in all three traces. The disturbance was characterized by a three-hour bay from about 09^h to 12^h in all elements, H and Z exhibiting depressions and D large westerly values. The bay was followed by about ten hours of rapid pulsations in all traces. One K-index of 7 and two of 6 were recorded.

Minimum H was 18,024 gammas at 14^h 16^m. Ranges: D, 45′; H, 185 gammas; Z, 265 gammas.

March 27-28—A mild storm began gradually at about 02^h GMT, March 27, moderate-amplitude, long-period oscillations occurring in all traces. After 02^h, March 28, more pronounced activity set in, all three traces being about equally disturbed. All traces had resumed normal positions by 18^h, March 28. Four K-indices of 6 were scaled for the first four intervals of March 28.

WILLIAM E. WILES, *Observer-in-Charge*

TUCSON MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1947

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or 7^h $23^m.3$ W. of Gr.)

January 16—A moderate storm of only about 20 hours' duration began suddenly at 03^h 30^m GMT, January 16, with increases of 35 gammas in H and 4′ in eastward D. The greatest disturbance in D and minimum values of H occurred between 15^h and 21^h. Ranges: H, 135 gammas; D, 18′.

January 24-26—A moderate storm began about 05^h GMT, January 24. The first twenty-two hours of the disturbance were characterized principally by small-amplitude, short-period variations. Following this phase the variations increased in both amplitude and period, but without other marked peculiarities. The storm ended with a gradual moderation of the disturbances about 15^h, January 26. Ranges: H, 152 gammas; D, 15½′.

February 16-17—A moderate storm began suddenly with an increase of 31 gammas in H at 03^h 00^m GMT, February 16. There were no outstanding characteristics of the storm other than general magnetic roughness. Most of the disturbance died out about Greenwich noon, February 17. Ranges: H, 120 gammas; D, 14½′; Z, 55 gammas.

March 2-4—An increase of 31 gammas in H, beginning at 04^h 01^m GMT, March 2, and requiring about six minutes for its completion marked the beginning of a severe storm. A second increase, 80 gammas, in H and requiring only three minutes began at 08^h 17^m, accompanied by a sudden disturbance in D and Z. During the following eighteen hours there was a considerable amount of large, irregular activity on which was superimposed a noticeable amount of short-period disturbance. The rapid fluctuations died out about 01^h, March 3, but the slower fluctuations with increased amplitudes continued until Greenwich noon on March 4. A slight amount of very rapid oscillations was in evidence from 11^h to 24^h, March 3. The principal activity ended about 12^h, March 4, but the rapid, small-amplitude disturbance again was recorded during the daylight hours of March 4 (latter half of Greenwich day). The storm ended about 21^h, March 4. Ranges: H, 310 gammas; D, 28′; Z, 82 gammas.

March 7-9—A moderately severe storm began with a small but definite increase of 16 gammas in H at 05^h 36^m GMT, March 7. The first twenty-four hours were only lightly disturbed—hardly of storm-intensity. Somewhat greater activity began about 01^h, March 8, consisting of fairly large swings in D and H on which were superimposed oscillations of short period. The rapid fluctuations died down about 21^h, March 8, but the large, irregular changes continued until about noon on March 9. The storm ended during the second half of the Greenwich day, March 9. Ranges: H, 214 gammas; D, 18½′; Z, 71 gammas.

March 15-17—Following a somewhat disturbed day on March 14, a sharp increase of about 45 gammas in H at 08^h 41^m GMT, March 15, marked the apparent beginning of a new storm that was to continue about forty-eight hours. Moderately large swings in D and H occurred during the first ten hours. From about 11^h until 22^h, there were rapid oscillations of amplitudes up to 10 or 15 gammas. From 00^h until 15^h, March 16, there were no large changes, but rapid, small-amplitude oscillations were in evidence. Following this period there were irregular, moderate variations until the end of the storm about Greenwich noon, March 17. Ranges: H, 111 gammas; D, 20½′.

March 27-28—A moderate storm began at 04^h 28^m GMT, March 27, with a sharp increase of 33 gammas in H. There were no outstanding characteristics; the disturbance consisted of irregular magnetic roughness, with a gradual ending during the last quarter of the Greenwich day, March 28.

J. H. Nelson, *Observer-in-Charge*

Zô-Sè Observatory

January to March, 1947

(Latitude 31° 05′.8 N., longitude 121° 11′.2 o[illegible]^h 04^m 45^s E. of Gr.)

January 1-2—At 03^h 12^m and 09^h 00^m GMT, January 1, there were two small abrupt changes followed by small disturbances during January 1 and 2.

January 4—There was an abrupt change of 45 gammas at 11^h 17^m GMT, January 4.

January 14-16—Pulses were recorded during 06^h 18^m to 07^h 00^m GMT, January 14, and during 00^h 42^m to 01^h 07^m, January 15. There was a small disturbance with sudden commencement of 25 gammas at 03^h 28^m, January 16.

January 24-28—There was a sudden commencement of 19 gammas at 06^h 20^m GMT, January 24, in a moderate storm during which values of H decreased by 112 gammas. Increased activity began at about 05^h, January 25 with a minimum of 192 gammas about 11^h 28^m, which was followed

by a large bay. H slowly recovered on January 26. Stormy conditions prevailed during 12^h, January 27 to 07^h, January 28.

February 7—At 08^h 14^m GMT, there was a small abrupt beginning with moderate activity.

February 16—A moderate storm began with an increase of H of 41 gammas; H then decreased until 08^h 00^m, when there was a rapid drop. The range of disturbance was 332 gammas.

February 23-24—A small pulse was recorded from 01^h 52^m GMT to 02^h 00^m, February 23. A small abrupt beginning of 10 gammas was recorded following a pulse at 01^h 15^m, February 24 with small activity.

March 1-2—A preliminary disturbance at 12^h 22^m GMT, March 1, followed by a few quiet hours, preceded a sudden commencement of 39 gammas at 04^h 00^m, March 2. There was rather strong disturbance during two days.

March 7-8—At 05^h 35^m GMT, March 7, there was a sudden change of some 20 gammas preceding moderate activity. About 06^h, March 8, H decreased and there was some activity.

March 10-14—About 02^h, 04^h, and 06^h GMT, March 10, small special marks in D and Z indicated a certain eruptive activity in the Sun. At 23^h 56^m, March 11, a preliminary beginning was followed by restricted activity and a sudden commencement began a moderate disturbance at 04^h 57^m, March 12. The range was small and disturbance lasted until 17^h, March 14.

March 15—There was a sudden increase of 24 gammas at 08^h 42^m preceding a small storm of short duration.

March 16-18—A pulse from 07^h 28^m GMT to 07^h 50^m, March 16, was followed by small activity during March 17 and 18.

March 27—A moderate disturbance occurred between 00^h 30^m GMT and 05^h, with small range. The record was interrupted at the moment of beginning.

M. Burgaud, *Director*

Huancayo Magnetic Observatory

October, 1946, to March, 1947

(Latitude 12° 02′.7 S., longitude 76° 20′.4 or 5^h $01^m.4$ W. of Gr.)

October 20—There was mild magnetic disturbance on October 20, characterized chiefly by having a "sudden commencement" in H at 03^h 08^m GMT, two small peaks between 15^h and 16^h, and a small peak and bay near 19^h. D and Z were only very slightly disturbed by small movements.

November 5-6—A magnetic disturbance began with a short, rapid increase in H at 09^h 23^m GMT, November 5, followed during the daylight hours of that day by small but rather rapid movements. The night hours

were almost quiet, but the daylight hours of November 6 were marked by three slow but rather moderate peaks and bays following each other from before 14^h to about 18^h, followed almost immediately by quiet conditions. Neither D nor Z showed any marked effects of the disturbance.

November 24—At $03^h\ 44^m$ GMT, November 24, there began a 55-gamma increase in H which was followed until after 13^h by slight disturbance only. Then, beginning at $13^h\ 09^m$ there was a very rapid increase of 210 gammas in five minutes, followed immediately by a 565-gamma decrease in twenty-nine minutes to a low bay at $13^h\ 43^m$. After another hour of sharp, small peaks and bays, which brought H back to a normal value for that time of the day, the disturbance died down with small, rapid movements during the night hours. D showed a range of $12'$ and Z a range of 57 gammas during the hour of greatest activity.

January 16—A short magnetic disturbance on January 16 began with a sudden commencement in H at $03^h\ 29^m$ GMT with an increase of 72 gammas in four minutes. It was characterized by an unusually high peak at $16^h\ 17^m$, 425 gammas above the base-line, but otherwise only moderate peaks and bays during the daytime hours. H had a range of 545 gammas during the disturbance, but there were only very mild effects on D and Z.

February 16—A short, "sudden-commencement" disturbance on February 16 began with a sharp increase in H at $02^h\ 59^m$ GMT, but was followed by nine hours of practically undisturbed record with a slow decrease in H. After this there were five hours of erratic, sharp peaks and bays, followed during the rest of the day by subnormal values but only weak disturbance. D and Z showed marked effects only during the height of the disturbance, and the range in H was only 316 gammas.

March 2-3—A sharp increase in H of 43 gammas at $04^h\ 00^m$ GMT, March 2, was followed by more than four practically undisturbed hours. Then began a storm which extended over two days and was characterized by rapid, moderate peaks and bays during the daylight hours of March 2 and 3, with only one sharp, deep bay at $14^h\ 05^m$, March 2. Low values in H were recorded during the night hours, but the variations were slow and moderate in height. The range in H was 540 gammas the first day, and 435 gammas the second day of the storm. D and Z were more than usually disturbed during the height of the disturbed hours, though the movements were small. The storm ended gradually during the early hours of March 4, and was followed by several days of normal recording but with subnormal values during the night hours.

March 8—A very sharp, short magnetic disturbance on March 8 began at about 12^h GMT, somewhat gradually, but was characterized by very rapid, long peaks and bays in H from 13^h to about 19^h, followed by a long decrease to a low value just after 24^h but only slightly disturbed during the night hours. Both D and Z showed rapid, short movements during the

height of the disturbance, and H recorded lower values than normal for the following few days. The range in H was 420 gammas.

March 15—A short, "sudden-commencement" disturbance began at $08^h\ 42^m$ GMT, March 15, with a small increase in H and Z, followed by nearly five hours of mildly disturbed low values in H, and then eight hours of very rapid, small movements superimposed on moderate peaks and bays. There was one high peak at $15^h\ 52^m$ and one deep bay at $17^h\ 00^m$. The range in H was 355 gammas.

Paul G. Ledig, *Observer-in-Charge*

Apia Observatory

October, 1946, to March, 1947

(Latitude 13° 48'.4 S., longitude 171° 46'.5 or $11^h\ 27^m.1$ W. of Gr.)

October 8-10—A mild disturbance emerged at $17^h\ 24^m$ GMT, October 8, and continued until $00^h\ 13^m$, October 10. Movement was irregular. A negative bay during the second three-hour period, October 9, gave the maximum K-index 5.

October 19-22—Activity began at $22^h\ 00^m$ GMT, October 19. A sudden commencement followed at $03^h\ 08^m$, October 20, movement fading out at $02^h\ 23^m$, October 21. A slight disturbance again emerged at $16^h\ 06^m$, October 21, followed by a sudden commencement at $21^h\ 09^m$, October 21. Very mild activity continued until $12^h\ 51^m$, October 22. Maximum K-index 5 occurred during the last three-hour period, October 19.

October 26-28—Irregular movement commenced at $06^h\ 00^m$ GMT, October 26, and faded out at $12^h\ 54^m$, October 28. K-indices of 5 were recorded during the last three-hour period, October 26, and the first three-hour period, October 27.

November 5-7—A sudden commencement at $09^h\ 21^m$ GMT, November 5, marked the onset of a period of mild, irregular activity which faded out at $00^h\ 35^m$, November 7. K-indices of 4 were recorded during the fourth and seventh three-hour periods, November 5, and the third three-hour period, November 6.

November 11-12—A sudden commencement at $11^h\ 24^m$ GMT, November 11, was followed by very slight activity which continued until $09^h\ 00^m$, November 12. The maximum K-index 5 occurred during the second three-hour period, November 12.

November 15-16—Mild activity, lasting until $06^h\ 36^m$ GMT, November 16, began with a sudden commencement at $07^h\ 54^m$, November 15. K-index 4 occurred during the third three-hour period, November 15

November 20-21—Mild activity emerged at $10^h\ 05^m$ GMT, November 20, and continued until $15^h\ 00^m$, November 21. Maximum K-index 5 occurred during the first three-hour period, November 21.

November 24-26—A sudden commencement at $04^h\ 47^m$ GMT, November 24, marked the beginning of a period of minor activity which faded out at $05^h\ 51^m$, November 26. Maximum K-index 5 was recorded during the fifth three-hour period, November 24.

December 18-20—Minor activity emerged at $22^h\ 55^m$ GMT, December 18, fading out at $01^h\ 30^m$, December 20. Maximum K-index 5 occurred during the third three-hour period, December 19.

December 21-23—Slight, irregular activity consisting of small, bay-like movement appeared on successive days, as follows: $08^h\ 00^m$ GMT, December 21; $05^h\ 00^m$, December 22; and $05^h\ 05^m$, December 23. Movement was apparent in both H and Z.

January 3-7—The traces became mildly disturbed at $21^h\ 02^m$ GMT, January 3. A sudden commencement followed at $11^h\ 18^m$, January 3, slight activity continuing until $13^h\ 11^m$, January 7. K-indices of 4 were recorded during the seventh and eighth three-hourly periods, January 5.

January 16-17—A sudden commencement occurred at $03^h\ 28^m$ GMT, January 16. Mild activity continued until $13^h\ 22^m$, January 17. A K-index of 5 was recorded during the seventh three-hourly period, January 16.

January 24-28—Mild activity developed at 05^h GMT, January 24, and was followed by stronger movement at $23^h\ 50^m$ on the same day. This introduced a period of moderate disturbance consisting of irregular bays and peaks, which abated at 14^h, January 26, and faded out at $07^h\ 30^m$, January 28. K-indices of 5 and 6 were recorded.

February 3-4—Slight movement which appeared at $22^h\ 55^m$ GMT, February 3, continued until 13^h, February 4. A K-index of 4 was recorded during the first three-hour period, February 4.

February 6-10—After a sudden commencement at $08^h\ 15^m$ GMT, February 6, minor activity persisted with periods of quiescence until $15^h\ 28^m$, February 10. K-indices of 4 were recorded on February 8, 9, and 10.

February 16-17—A moderate disturbance followed a sudden commencement at $03^h\ 03^m$ GMT, February 16. Irregular movement continued with a gradual return to normal conditions at 20^h, February 17. K-indices of 6, 5, 5 were recorded during the fourth, fifth, and sixth three-hour periods, February 16.

March 2-4—A stormy period followed a sudden commencement at 04^h GMT, March 2. Activity was greatest during the fourth three-hour periods on March 2 and March 3, when K-indices of 7 were recorded. Movement consisted of irregular peaks and bays, normal conditions returning at 24^h, March 4. H remained slightly lower than usual.

March 7-9—A small sudden commencement at $05^h\ 39^m$ GMT, March 7, was followed by mild activity which became stronger at 08^h, March 8. Disturbed conditions subsided at 19^h, March 9. K-indices of 5 were re-

corded during the third, fourth, fifth, and sixth three-hour periods, March 8, and the third period, March 9.

March 12-17—Minor activity followed a small sudden commencement at $04^h\ 56^m$ GMT, March 12, and continued until $08^h\ 45^m$, March 15, when a sharp sudden commencement began a more active period. Conditions became more settled at $04^h\ 00^m$, March 16, but H remained very low. A further slightly-disturbed period began on March 17, dying out at 12^h, March 17. K-indices of 5 and 6 were recorded on March 15.

March 22-31—Traces were mildly disturbed over a considerable period during the latter part of the month of March. Minor activity began at 03^h GMT, March 21, and continued with brief periods of quiescence until 04^h, 28^m, March 26, when a sudden commencement introduced a moderate disturbance. The trace became less disturbed at 06^h GMT, March 29, but H remained low, further activity developing at $21^h\ 45^m$, March 25, and continuing until $16^h\ 36^m$, March 31. K-indices of 5 were recorded on March 22, 28, and 29, and a K-index of 6 during the third three-hour period, March 28

J. W. BEAGLEY, *Director*

ALIBAG MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1947

(Latitude 18° 38′.3 N., longitude 72° 52′.3 or $4^h\ 51^m.5$ E. of Gr.)

January 16-17—A sudden-commencement disturbance began at $03^h\ 27^m$ GMT, January 16, and continued until about 01^h, January 17. The initial stage of the disturbance was characterized by small fluctuations in all the three elements. One K-index of 6 and one of 5 were recorded during the disturbance. Ranges: D, 5′.8; H, 153 gammas; Z, 58 gammas.

January 24-26—A disturbance which began at about $04^h\ 30^m$ GMT, January 24, continued until about 00^h, January 25, after which moderate fluctuations were recorded until about 05^h, H decreasing thereafter with intermittent rise and fall. The disturbance ended at about $20^h\ 30^m$, January 26, and yielded two K-indices of 6 and three of 5. Ranges: D, 5′.8; H, 258 gammas; Z, 64 gammas.

February 16-17—Preceded by a period of very quiet conditions, a storm of great intensity began with a sudden commencement at $02^h\ 59^m$ GMT, February 16, with a sharp increase of 33 gammas in H and a fall of 11 gammas in Z within four minutes. After that H rose gradually with small fluctuations until about $08^h\ 15^m$, when it fell rapidly at a more or less uniform rate until about $13^h\ 10^m$, large fluctuations not being in evidence during the fall. H became fairly steady thereafter until about $16^h\ 20^m$, when it gave a swing which resulted in a rise of 121 gammas in about an hour's time. After recording small-amplitude fluctuations the disturbance

ended at about $15^h 30^m$, February 17, recording one K-index of 8 surrounded by one of 6 and two of 5. Ranges: D, 5′.1; H, 366 gammas; Z, 88 gammas.

March 2-4—A sudden rise of 35 gammas in H and fall of 8 gammas in Z marked the beginning of a storm at $03^h 59^m$ GMT, March 2. H was fairly steady until $08^h 16^m$, March 2, when it suddenly increased by 68 gammas in less than a minute and very rapid fluctuations were recorded thereafter until $10^h 12^m$, March 2, after which H fell fairly rapidly until about $13^h 50^m$. The disturbance continued until $09^h 30^m$, March 4, recording during the storm one K-index of 8, two of 7, four of 6, and four of 5. Ranges: D, 7′.8; H, 434 gammas; Z, 77 gammas.

March 8—A moderate disturbance with a gradual commencement started at about 06^h GMT, March 8. After recording some large fluctuations, the disturbance practically ended at about 22^h. The highest K-index recorded during the disturbance was 6 for the successive intervals between 15^h and 21^h. Ranges: D, 4′.1; H, 330 gammas; Z, 45 gammas.

March 15—A disturbance of very short duration suddenly started at about $08^h 42^m$ GMT, March 15, and ended at about $16^h 30^m$, giving only two K-indices of 6 and one of 5 during the disturbed period. Ranges: D, 4′.6; H, 199 gammas; Z, 35 gammas.

M. P. Rao, *Assistant*

Watheroo Magnetic Observatory
January to March, 1947

(*Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h 43^m.5$ E. of Gr.*)

January 4-5—A sudden commencement was recorded at $11^h 18^m$ GMT, January 4. The horizontal intensity increased by 41 gammas in one minute, west declination decreased by 1′ and then increased by 4′, while the vertical intensity showed a sudden decrease of 3 gammas followed by an increase of 16 gammas. H dropped fairly sharply by 69 gammas in the next hour, whereas D and Z recovered their original values within about ten minutes of the commencement. For the next eleven hours all elements showed large irregular movements without departing appreciably from normal values. From $22^h 30^m$, January 4, until 04^h, January 5, conditions were quiet. Moderately disturbed conditions prevailed again from 04^h onward, with small, rapid fluctuations at first followed by large, slow swings which died away by about 22^h, January 5. At this stage the elements were practically normal again. However, conditions were a little unsettled for a further period of about twenty hours. Ranges: D, 14′; H, 83 gammas; Z, 86 gammas.

January 16-17—A fairly severe storm of short duration commenced suddenly at $03^h 30^m$ GMT, January 16. The value of H increased by 25 gammas, then decreased by 74 gammas, in three minutes. Part of this movement

was too rapid to record on the Eschenhagen magnetograph and was measured from the la Cour magnetogram. After an increase of 25 gammas, H dropped rapidly by a further 60 gammas to a minimum at $03^h\ 55^m$. H recovered very quickly to a value above normal, increasing by 152 gammas to a maximum at $05^h\ 35^m$. All three elements were moderately disturbed with irregular movements until 13^h, January 17. Ranges: D, 19′; H, 164 gammas; Z, 114 gammas.

January 24-27—At $06^h\ 20^m$ GMT, January 24, a disturbance commenced with a sudden decrease of 3 gammas in H, followed by a rapid increase of 23 gammas in the next minute. H continued to increase until $06^h\ 35^m$ and then dropped during the next two hours. D and Z did not change suddenly at $06^h\ 20^m$ and both showed little movement until $07^h\ 50^m$. For the next four hours all three elements were only slightly disturbed. Conditions were quiet from 10^h until 15^h, when small, rapid fluctuations of all elements set in, becoming more rapid and of larger amplitude at 24^h, January 24. Throughout the whole of January 25 the elements showed continuous variations of small amplitude superimposed upon large swings. During January 26, the degree of disturbance became somewhat less, but H was depressed considerably below its normal value with irregular fluctuations. There was a noticeable recovery around 04^h, January 27, and conditions were again almost normal by 07^h and the storm was effectively over. However, there were further small, rapid fluctuations from 13^h, January 27, to 08^h, January 28, by which time all traces of this prolonged disturbance had disappeared. Ranges: D, 27′; H, 185 gammas; Z, 163 gammas.

February 7-9—A moderate disturbance commenced fairly suddenly at $08^h\ 15^m$ GMT, February 7. H was momentarily depressed by 2 gammas and then increased by 33 gammas in the next three minutes. D moved 2′ eastward between $08^h\ 15^m$ and $08^h\ 18^m$, and then began a slow recovery westward. Z decreased by 9 gammas at the same time, and then slowly increased. The movements for the next twelve hours were of small magnitude and short duration. From 20^h normal conditions prevailed for a period of ten hours until 06^h, February 8, when slow, irregular movements commenced. These continued in all elements with increasing amplitude. Toward the end of the day the variations decreased in amplitude and increased in rapidity for a period of two hours ending at 24^h. The values of all three elements remained somewhat abnormal for a further twelve hours, but were practically back to normal by $12^h\ 00^m$, February 9, at which time the storm ended. However, there was some further slight disturbance during the following twenty-seven hours. Ranges: D, 18′; H, 103 gammas; Z, 100 gammas.

February 16-17—A fairly severe disturbance commenced suddenly at $03^h\ 59^m$ GMT, February 16. H increased by 10 gammas in less than a

minute and fluctuated about this level for perhaps half a minute before increasing a further 12 gammas. Z decreased by 6 gammas in the first minute, then increased by 10 gammas rapidly, after which there followed a fairly sharp decrease. D moved 1′ eastward and then 3′ westward. After the sudden commencement D and Z were fairly steady until 08^h, when small, rapid fluctuations set in as a preliminary to slower and larger movements. H showed small, irregular variations throughout this period and reached a sharp maximum at $08^h\ 12^m$, after which it showed a marked and irregular decrease, falling by 209 gammas between $08^h\ 12^m$ and $12^h\ 50^m$. H stayed at this low level for the next four hours, reaching its minimum for the storm at $16^h\ 20^m$, after which it rapidly increased half way towards normal. Z increased by 155 gammas between $07^h\ 54^m$ and $12^h\ 55^m$. D remained comparatively normal throughout except for large, slow swings. These were a feature of all three elements until 17^h, when they decreased in magnitude and increased in frequency. Conditions were unsettled until about 18^h, February 17, by which time all elements had returned to normal. Ranges: D, 21′; H, 212 gammas; Z, 191 gammas.

March 2-5—A rather severe disturbance commenced at $04^h\ 01^m$ GMT, March 2. H increased by 8 gammas and then dropped 7 gammas in four minutes before gradually increasing again. Z decreased by 2 gammas and then rose by 7 gammas before a further decrease began. D moved 3′ westward in four minutes. Conditions were relatively quiet for the next four hours except for a deep bay in H between 07^h and 08^h. Violent movements commenced suddenly at $08^h\ 17^m$ in all elements, principally in H, which decreased by 33 gammas and then increased by 103 gammas, the whole movement taking place within a minute. H reached its maximum for the storm at $08^h\ 40^m$. Thereafter, movements were large, rapid and irregular until, at $10^h\ 05^m$, H decreased rapidly by 146 gammas in seven minutes. Z increased by 67 gammas and D moved 10′ westward at the same time. Following this burst of activity, H recovered somewhat to about a normal value at $10^h\ 58^m$. It then decreased steadily with a few fluctuations through a range of 160 gammas by $13^h\ 35^m$. There followed a rapid increase to a peak at $14^h\ 44^m$. Z showed a somewhat parallel disturbance. Thereafter, the movements of all elements were very irregular, increasing in frequency and decreasing in amplitude until 03^h, March 3. Quiet conditions prevailed for the following three hours when slow, irregular variations of large amplitude commenced. At 23^h, March 3, the fluctuations became smaller but of shorter period, and continued with gradually decreasing amplitude until about $07^h\ 50^m$, March 5. H reached its minimum for the storm at $05^h\ 18^m$, March 4. Ranges: D, 27′; H, 308 gammas; Z, 181 gammas.

March 7-9—A moderate disturbance commenced at $05^h\ 36^m$ GMT, March 7. H was momentarily depressed by 5 gammas and then increased by 12 gammas in the following four minutes. D and Z decreased slightly.

Small, irregular movements followed with little departure from normal until $04^h\ 20^m$, March 8, when there was a pronounced bay in D and Z over a period of eighteen minutes. Variations in H began just before 06^h and increased in frequency. From 08^h onward H began to decrease, the tendency continuing until a minimum was reached at $13^h\ 33^m$ giving a range of 179 gammas. At $14^h\ 33^m$ H rapidly increased by 145 gammas in fifteen minutes and then dropped again by half that amount. D showed a westward swing commencing at $14^h\ 27^m$ and reaching a sharp peak at $14^h\ 44^m$ before recovering by a swing of 22′ toward the east. Simultaneously Z showed a maximum at $14^h\ 44^m$ followed by a rapid decrease of 116 gammas. Slow, large variations continued in all elements until 24^h, March 8, with H depressed well below normal. H increased during the next eight hours, showing a particularly marked recovery between $08^h\ 40^m$ and $09^h\ 00^m$, March 9. Conditions were practically normal again by $09^h\ 10^m$, March 9, although there was a little unsteadiness during the following twenty-four hours. Ranges: D, 33′; H, 188 gammas; Z, 249 gammas. An aurora was observed at Watheroo on the night of March 8. It was first noticed at $14^h\ 40^m$ as a deep pink glow in two areas, one slightly east of south and the other to the south-southwest. The two areas merged after ten minutes into a uniform pink glow which faded out by $15^h\ 15^m$.

March 15—A short disturbance of moderate intensity had a sudden commencement at $08^h\ 41^m$ GMT, March 15. H suddenly increased by 24 gammas and more slowly by a further 15 gammas. D moved 3′ east, and Z decreased by 17 gammas in two minutes. Small movements, superimposed on slow, large variations continued for nine hours, Z showing a sharp peak at $10^h\ 45^m$ and a sharp bay at $15^h\ 41^m$. Except for numerous very small, rapid fluctuations which continued until about 12^h, March 16, conditions were normal by 18^h, March 15. Ranges: D, 26′; H, 133 gammas; Z, 176 gammas.

March 27-28—A moderate disturbance commenced at $04^h\ 28^m$ GMT, March 27, with sudden movements in all three elements. H increased by 6 gammas and then more slowly by another 14 gammas; Z increased by 3 gammas, and D moved 1′ west, simultaneously. The fluctuations for the next seven hours were irregular and at times fairly rapid but without much departure from the normal level. From 12^h until $16^h\ 30^m$, H was the only element to show any movement of more than 2 gammas. Between $16^h\ 30^m$ and 18^h there were three series of "giant micropulsations" in all elements. Disturbed conditions prevailed with decreasing amplitude to 23^h, March 28, when the storm ended. D reached a peak at $12^h\ 58^m$, March 28, Z showing a sharp peak at the same time. Ranges: D, 23′; H, 110 gammas; Z, 154 gammas.

F. W. Wood, *Observer-in-Charge*

Hermanus Magnetic Observatory

January to March, 1947

(Latitude 34° 25′.2 S., longitude 19° 13′.5 or 1ʰ 16ᵐ.9 E. of Gr.)

January 4-6—A storm of moderate intensity began with a sudden commencement at 11^h 17^m GMT, January 4 (H, 39 gammas in seven minutes), and continued until about 16^h, January 6. Five K-indices of 5 were recorded during that period.

January 16—A large, sudden commencement at 03^h 29^m GMT, January 16 (H, 46 gammas in five minutes), was followed by a storm of moderate intensity which subsided at about 23^h. Ranges: D, 28′; H, 166 gammas; Z, 124 gammas.

January 24-28—A prolonged disturbance of moderate intensity, which began with abrupt changes in the elements at 06^h 20^m GMT, January 24, persisted until about 03^h, January 28. A K-index of 6 was recorded at the beginning of the storm. Two rapid changes, equal in magnitude but opposite in sign, occurred at 23^h 50^m, January 24, and 01^h 05^m, January 25, respectively.

February 3-4—Minor disturbances were recorded between 18^h GMT, February 3, and 14^h, February 4.

February 7-8—A storm of moderate intensity, heralded by abrupt changes in the elements at 08^h 14^m GMT, February 7, did not develop until about 06^h, February 8, although an abnormally large range in D gave rise to a K-index of 5 for the three-hour period 09^h-12^h, February 7. The main phase of the storm ended at 24^h, February 8, although minor activity continued until 16^h, February 10.

February 16-17—A disturbance of moderate intensity began with a sudden commencement at 02^h 59^m GMT, February 16, ending rather abruptly at 09^h, February 17.

February 19-20—Minor disturbances were recorded between 12^h GMT, February 19, and 06^h, February 20.

February 24—Sudden changes in the elements occurred at 01^h 13^m GMT, February 24 (H, 16 gammas in eight minutes), but the expected storm did not develop.

March 2-5—A storm of considerable violence began with a sudden commencement at 04^h 01^m GMT, March 2 (H, 28 gammas in six minutes), and continued until about 15^h, March 4, although minor activity persisted for a further twenty-four hours. H reached its maximum, Z its minimum numerical value, at 09^h 30^m, March 2. The large deflections in H and Z between 09^h 00^m and 09^h 12^m, March 2, correspond to a violent 20′ upward swing of the north end of a "free" needle. The accompanying effect in D was negligible. Strong movements were recorded on all three traces during

the eighth three-hour period of March 2, and during the first, seventh, and eighth of March 3. Ranges: D, 28′.8; H, 323 gammas; Z, 204 gammas.

March 7-10—Minor activity followed the small abrupt changes recorded at $05^h\ 35^m.5$ GMT, March 7, until, almost exactly twenty-four hours after the first warning, a storm of moderate intensity broke out at about $05^h\ 30^m$, March 8. By 04^h, March 9, the main phase of the storm was past, but minor activity continued until 07^h, March 10. On March 8 the ranges were as follows: D, 33′.5; H, 223 gammas; Z, 127 gammas.

March 12-14—An abrupt change in H at $04^h\ 58^m$ GMT, March 12, with accompanying slight effects in D and Z, was followed by moderately disturbed conditions which continued until 18^h, March 14. Rapid movements were recorded between $12^h\ 04^m$ and $12^h\ 20^m$, March 12, and between $08^h\ 24^m$ and $12^h\ 40^m$, March 13.

March 15—A brief storm of moderate intensity began with a sudden commencement at $08^h\ 41^m$ GMT, March 15. The main phase of the storm was over by 18^h, March 15, by which time three K-indices of 5 and one of 6 had been recorded.

March 16-17—The period from 17^h GMT, March 16, to 07^h, March 17, was characterized by bays, the largest of which began abruptly at $00^h\ 27^m$, March 17, yielding a K-index of 5.

March 22-24—Prominent among the minor disturbances recorded during the GMT period 03^h, March 22, to 11^h, March 24, was a large three-hour bay in H and Z between 15^h and 18^h, March 23.

March 25-31—A period of minor activity which began at about 20^h GMT, March 25, was followed at $04^h\ 29^m$, March 27, by a storm of moderate intensity. The disturbance subsided at 01^h, March 29, but broke out again at $19^h\ 20^m$ on the same day. Moderately disturbed conditions, characterized by one-hour bays in all three elements, prevailed until 16^h, March 31. The five most prominent bays began at the following times: $02^h\ 30^m$, $12^h\ 50^m$, $22^h\ 13^m$, March 28; $19^h\ 20^m$, March 29; $00^h\ 20^m$, March 30.

A. M. van Wijk, *Officer-in-Charge*

NOTES

(15) *Joint meeting, American Section of International Scientific Radio Union and Institute of Radio Engineers* —This joint meeting was held in Washington, D. C., on May 5, 6, and 7, 1947. Some 98 papers were presented in sessions on groups of subjects as follows: Communication systems, modulation, and radar; Navigation, control, and telemetering; Ionospheric propagation; Measurement methods; Geophysical and cosmic phenomena; Circuits; Microwave propagation; Theory calculations and vacuum tubes; and Antennas.

(16) *Conference on radio propagation, Central Radio Propagation Laboratory*—Following the above-noted joint meeting a conference on radio propagation was held at the National Bureau of Standards, Washington, D. C., on May 8, 9, and 10, 1947. There were no formal papers but there were six general subjects discussed as follows: Ionospheric measurement technique and problems; Ionospheric propagation analysis and prediction; Physics of the ionosphere; Effects of the Sun on the ionosphere; Cosmic noise; and Propagation at VHF and higher frequencies.

(17) *Annual meeting of the National Academy of Sciences*—The annual meeting of 1947 of the Academy on April 28 to 30, 1947, heard 20 scientific papers. Of interest to readers of the JOURNAL were: Solar effects in cosmic rays, by S. E. Forbush; Relativistic correction to the magnetic moment of the deuteron, by G. Breit and I. Block.

Elected as member of the Academy on April 30, 1947, was Dr. J. A. B. Bjerknes.

(18) *Twenty-eighth annual meeting of the American Geophysical Union*—The twenty-eighth annual meeting of the American Geophysical Union and its Sections was held in Washington, D. C., during April 28, 29, and 30, 1947. Some 750 members and guests were in attendance at 15 sessions.

A total of 129 papers and reports of Special Scientific Committees was presented. The address of Retiring President L. H. Adams at the evening General Assembly on the evening of April 30 was on Some of the great, unsolved problems of geophysics in the Elihu Root Memorial Hall of the Carnegie Institution of Washington. This address was followed by the Ninth Annual Award of the William Bowie Medal to Dr. F. A. Vening Meinesz of Holland. The citation was by Dr. F. E. Wright, with presentation of the Medal, in the absence of Dr. Vening Meinesz, by President Adams to H. A. Helb, Counselor of the Netherlands Embassy to the United States.

Professor J. Tuzo Wilson of the Department of Geophysics of the University of Toronto, Canada, addressed the General Assembly on the after-

noon of April 30 on Some aspects of geophysics in the Canadian Shield, with special reference to structural research. This address was followed by reports upon the work of the International Commission on Continental and Oceanic Structure and of the International Committee on the Social Value of the Earth's Sciences, by Dr. Richard M. Field, who is Chairman of both.

The numbers of papers presented before individual Sections were: Geodesy, 12; Seismology, 11; Meteorology, 10; Terrestrial Magnetism and Electricity, 21; Oceanography, 26; Volcanology, 6; Hydrology, 24 and 13 Research-Committee reports; Tectorophysics, 4.

The papers will all be published, either in full or in abstract in the coming year's issues of the bimonthly *Transactions* of the Union. Those of especial interest to readers of the Journal were presented before the Section of Terrestrial Magnetism and Electricity as follows:

Remarks on the Schrödinger unitary field theory as applied to the Earth's and Sun's permanent magnetic field, by E. H. Vestine (Carnegie Institution of Washington, Department of Terrestrial Magnetism); The properties of the saturable inductor as a detector for measuring magnetic fields, by L. H. Rumbaugh (Naval Ordnance Laboratory); The orientation problem in continuously recording mobile magnetometers, by E. O. Schonstedt (Naval Ordnance Laboratory); The design of saturable inductor type magnetometers, by L. R. Alldredge (Naval Ordnance Laboratory); The correlation of magnetometer records with flight paths in aerial magnetic mapping, by J. M. Klaasse (Naval Ordnance Laboratory); Magnetic anomalies over oceanic structures, by Frank Press and Maurice Ewing (Columbia University and Woods Hole Oceanographic Institution); Problems of magnetic mapping, by Elliott B. Roberts (United States Coast and Geodetic Survey); A new station-type magnetometer, by Roland F. Beers (The Geotechnical Corporation, Dallas, Texas) and Harold R. Larsen (W. & L. E. Gurley Co., Troy, N. Y.); Atmospheric-electric phenomena at Parícutin Volcano, by O. H. Gish (Carnegie Institution of Washington, Department of Terrestrial Magnetism); Current magnetic work of the United States Coast and Geodetic Survey, by Elliott B. Roberts (U. S. Coast and Geodetic Survey); Some fundamental processes of geophysical interest in oxygen and nitrogen, by Joseph Kaplan (Institute of Geophysics, University of California); Polar radio disturbances during magnetic bays, by H. W. Wells (Carnegie Institution of Washington, Department of Terrestrial Magnetism); Relations of ion density in the *D*-region to the sunspot-cycle as inferred from radio-wave absorption and variations in terrestrial magnetism, by M. B. Harrington (Central Radio Propagation Laboratory, National Bureau of Standards); Statistical study and prediction of annual sunspot-numbers, by A. G. McNish and J. V. Lincoln (Central Radio Propagation Laboratory); Variability of noon values of $F2$

critical frequency at different ionosphere stations, by T. N. Gautier (Central Radio Propagation Laboratory); Possible effect of terrestrial magnetic variations on ion density in the *F*2 layer, by A. G. McNish (Central Radio Propagation Laboratory); V-2 ionosphere studies by the Naval Research Laboratory, by T. R. Burnight (Naval Research Laboratory); New high-altitude solar ultraviolet spectra, by E. Durand, F. S. Johnson, J. J. Oberly, C. C. Rockwood, and R. Tousey (Naval Research Laboratory); The electrical conductivity of air irradiated by ultraviolet light, by G. R. Wait (Carnegie Institution of Washington, Department of Terrestrial Magnetism); Recent studies of radio field-intensity measurements at the Cosmic Terrestrial Research Laboratory, Needham, Massachusetts, by Harlan T. Stetson; and Magnetic measurements at Little America, by H. Herbert Howe (U. S. Coast and Geodetic Survey).

(19) *United States Navy Antarctic Expedition*—Lt. Chas. A. Schoene and Dr. H. Herbert Howe were representatives of the United States Coast and Geodetic Survey on the recent Navy Antarctic Expedition, known as Operation Highjump. On the southward journey, Dr. Howe observed dip at one point on the pack-ice. At Little America IV, Lt. Schoene and Dr. Howe operated a magnetograph for vertical intensity during January 29 to February 22, 1947, and also made absolute observations of total intensity, dip, horizontal intensity, and declination. After leaving Little America, Dr. Howe had planned to make observations on Scott Island. However, rough water prevented making a landing there, although considerable time was spent in the vicinity. On the return trip, he standardized instruments at Amberley Magnetic Observatory, near Christchurch, New Zealand, and also made observations at the secular-variation station at Old Panama. The flagship of the expedition, the *Mount Olympus*, sailed from Norfolk on December 2, 1946, and docked at Washington on April 14, 1947.

Final values for Little America IV cannot be derived until after the standardizations at Amberley are computed. The following preliminary values give the mean annual change for the interval 1940-47: Declination, $5'$ per year in the counterclockwise sense; south dip, decreasing $4'$ per year; horizontal intensity, increasing 70γ per year; vertical intensity, numerically decreasing 100γ to 170γ per year. Notwithstanding much popular speculation on the subject, these results were reported by Dr. Howe to have little or no bearing on the position or motion of the South Magnetic Pole, which is situated more than 1000 miles from Little America.

(20) *Magnetic survey of New Zealand*—Director H. F. Baird of the Christchurch Magnetic Observatory writes that, beginning January 18, 1947, he had spent some six weeks in field-work over North Island, New Zealand. Stations at Eketahuna, Opotiki, Te Awamutu, Featherstone, Cabbage Bay, Awanui, Helensville, and Pukearuhe were reoccupied. New stations were established at Port Jackson (head of Coromandel Peninsula)

and Omapere (near outlet of Hokianga Harbor). CIW combined magnetometer-inductor 27 was used for the observations. Comparisons at the Amberly Observatory of Christchurch show close agreement of CIW 27 with the standards there. The loan of CIW 27 is being continued to undertake further magnetic work in the South Island and for study of the volcanic area in the center of the North Island.

(21) *Geophysical Observatory in Swider*—One of the greatest losses, which the Geophysical Observatory in Swider suffered because of the war (according to a circular of January, 1947), was the nearly complete destruction of its library of theoretical works on geophysics and reports of analogous institutions abroad. The loss is the greater because those publications have, for the most part, not been on the commercial market and cannot be replaced by purchase. The first publication of the Observatory after the war No. 10 of "Travaux de l'Observatoire Géophysique à Swider", will be gladly sent in exchange for publications of all like institutions to include if possible complete files of earlier publications from each to replace those destroyed. The Observatory's staff is now preparing several volumes on their work during 1937-46, which it is hoped can be ready for distribution soon.

(22) *Transfer to new Honolulu Magnetic Observatory*—At the Honolulu Magnetic Observatory of the United States Coast and Geodetic Survey the instruments were transferred in March, 1947, to the new buildings on Barbers Point. The site near Ewa, which has been used for over 45 years, was directly in line with a heavily used airfield runway, necessitating abandonment of magnetic work there.

(23) *Permanent magnetic observatory at College, Alaska*—The plans and specifications for a complete magnetic observatory to be erected at College, near Fairbanks, Alaska, were recently approved and advertised for bids, with the cooperation of the United States Engineer Corps. Commander W. D. Patterson has been designated to be the representative of the Coast and Geodetic Survey during construction, which was scheduled to begin this summer. Commander Patterson performed a similar function some time ago in connection with the present buildings at the Sitka and Tucson Observatories, and more recently those at the Honolulu Observatory. When completed, the Observatory is expected to function in close cooperation with the projected Geophysical Institute of the University of Alaska.

(24) *Repository of geomagnetic data in the United States*—The United States Coast and Geodetic Survey has long been recognized as an important repository of geomagnetic data from world-wide sources. Formal arrangements are well advanced for the official recognition of the Bureau as the central agency of the Government for fulfillment of this function, and the necessary intensification and expansion of this work are under way.

(25) *Magnetic publication of United States Coast and Geodetic Survey*—

The publication "Directions for Magnetic Measurements" by D. L. Hazard [U. S. Coast Geodetic Surv. Ser. 166] has been reprinted by lithography with a few corrections.

(26) *School of Cosmic Physics in Dublin*—A school of Cosmic Physics in the Dublin Institute for Advanced Studies has been established by an Order made by the Irish Government on March 26, 1947.

This is the third constituent School of this Institute and will consist of three sections, dealing, respectively, with Geophysics including Meteorology and Astrophysics including Astronomy and Cosmic rays.

Professor John J. Nolan, M.A., D.Sc., Professor of Experimental Physics, University College, Dublin, was appointed Chairman of the Governing Body of the School and the following were appointed Senior Professors: H. A. Brück, Ph.D., hitherto Assistant Director, Cambridge Observatory; L. Janossy, Ph.D., hitherto Imperial Chemical Industries Fellow at Manchester University; L. W. Pollak, Ph.D., M.R.I.A., hitherto Senior Meteorological Officer in the Irish Department of Industry and Commerce. Professor Pollak was appointed Director of the School.

The objects of the School will be to carry out theoretical, observational, and experimental investigations on the subjects mentioned above, to collect and publish observational data referring to them, and to train advanced students in the methods of original research. A further aim of the School will be to cooperate with similar scientific institutions or individual research-workers in other countries and to arrange for exchange of advanced students with them.

The School will be accommodated partly in Dublin (5, Merrion Square), partly in the Dunsink Observatory near Dublin.

(27) *Transfers of the Watheroo and Huancayo Magnetic Observatories*—In view of the policy adopted by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington [Terr. Mag., **51**, 523-524 (1946)], arrangements have now been completed under which the Watheroo Magnetic Observatory will be transferred to the Department of Scientific and Industrial Research of the Australian Commonwealth on July 1, 1947. Mr. F. W. Wood will continue as Observer-in-Charge at Watheroo after the transfer.

Dr. J. A. Fleming, Adviser in International Scientific Relations to the Carnegie Institution visited Lima, Peru, and the Huancayo Magnetic Observatory during May 4 to 24, 1947, to conclude preliminary agreement for the transfer of the Huancayo Magnetic Observatory to the Government of Peru on July 1, 1947. This agreement is for the Observatory to be placed under the Ministry of Public Works of Peru and to be in charge of a Directive Committee of four citizens of Peru and three of the United States. The Chairman of the Committee is the Director of the Geological Institute of Peru. The present staff of the Observatory will continue with Paul

G. Ledig as Observer-in-Charge until late in December 1947, when he will be succeeded by Albert Giesicke, Jr., who is now First Assistant. After July 1, 1947, the Observatory will be renamed the Geophysical Institute of Huancayo (Instituto Geofisico de Peru). The President of Peru and his Council of Ministers are much interested in maintaining the highest standards in the new Institute. It is gratifying to note the wide interest of eminent Peruvian scientists in the geophysical fields. The Carnegie Institution of Washington will give about half of maintenance costs until June 30, 1949, after which time all expenses will be borne by the Government of Peru.

(28) *Magnetic disturbances and auroras, reported in Hydrographic Bulletin*—The following notes are extracted from *Hydrographic Bulletins* 3003, 3008, and 3010 of 1947:

The Commanding Officer of the U. S. Coast Guard Cutter *Wachusett* reports as follows: At $21^h\ 30^m$, zone plus 11 time, January 20, 1947, while steering 122° (true) en route from Massacre Bay, Attu to Amchitka, Aleutian Islands, the magnetic compass had an error of 2° E. This error changed erratically until at $23^h\ 50^m$ in approximately lat. 51° 40′ N., lon. 174° 25′ E., it was 25° W. During the next hour the error decreased to normal. Average variation during this time was 3.5° E. The ship was rolling deeply and was considerably iced down. Subsequent azimuths showed no gyrocompass error.

Officers W. Boehmer, R. Reynolds, and R. Oldershaw of the American SS *Santa Teresa*, Captain S. Koppang, report as follows: At $15^h\ 30^m$ GCT, February 13, 1947, in lat. 32° 42′ N., lon. 71° 30′ W., while steering 168°, a magnetic disturbance was experienced which caused the ship's magnetic compasses to fluctuate 30°. At $03^h\ 30^m$, February 14, 1947, in lat. 29° 45′ N., lon. 70° 50′ W., the compasses became steady and remained so thereafter. The magnetic compasses were checked every half hour with the gyrocompass.

The Master of the American SS *Adelphi Victory* reports as follows: On April 16, 1947, at approximately $22^h\ 00^m$ GCT, in lat. 32° 25′ N., lon. 34° 18′ W., a display of the Aurora Borealis in the form of bright reddish-gray curtains of light with white streamers of light was observed in the northern sky, extending from 340° to 20°, which disappeared gradually.

Second Officer Fausto Serradas of the Portuguese motor ship *Nacala*, Jose de Castro, Master, reports as follows: At $21^h\ 36^m$ GCT, April 17, 1947, in lat. 37° 44′ N., lon. 13° 16′ W., en route from Galveston, Texas, to Lisbon, Portugal, an unusual display of the Aurora Borealis was observed. This display covered an area of 65° of the horizon, from 325° to 30°, and at an altitude from 10° to 25° above the horizon, with two prominent light streamers perpendicular to the horizon. Between the two light streamers a distinct, deep-red color was observed, the maximum intensity occurring at $21^h\ 57^m$ GCT. The display ended at $22^h\ 33^m$.

(29) *Personalia*—Professors *C. Y. Chao* and *T. H. Pi*, of the Department of Physics, National Central University, Nanking, China, will work until late summer as Guest Investigators, with the nuclear physics group at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

Dr. *J. A. Fleming* was elected an Honorary Member of the Geological Society of Peru on May 17, 1947. He addressed the Society on "Earth sciences in Peru." During his visit, Dr. Fleming was also made an Honorary Member of the Geographical Society of Lima (Peru).

Mark W. Jones, Observer of the Department of Terrestrial Magnetism, who has been stationed at the Huancayo Magnetic Observatory since December 6, 1940, following his return on April 17, 1947, to Washington resigned to take up graduate work.

Kenneth L. Sherman, Physicist of the Department of Terrestrial Magnetism resigned April 25, 1947, in order to accept a position with the United States Navy Mine Countermeasures Station at Panama City, Florida.

James H. Baden, Jr., Geophysicist of the United States Coast and Geodetic Survey, is making magnetic observations in South America.

Merril L. Cleven, Geophysicist of the United States Coast and Geodetic Survey, will make magnetic observations in northern Alaska in the early summer of 1947.

Laurie M. Burgess, Geophysicist of the United States Coast and Geodetic Survey, reported for duty at the Honolulu Magnetic Observatory on March 24.

The Reverend *W. L. S. Fleming*, Fellow, Dean and Chaplain of Trinity Hall, Cambridge, has been appointed to succeed Professor F. Debenham as Director of the Scott Polar Research Institute. He was Chaplain and Geologist of the British Graham Land Expedition of 1934-37, following work with the Cambridge Iceland Expedition of 1932 and with the Oxford University Arctic Expedition to Spitsbergen in 1933.

Sir *Thomas Henry Holland*, retired Principal and Vice-Chancellor, Edinburgh, and a leading geologist and mineralogist, died May 17, 1947, aged 78 years. Sir Thomas was formerly Director of the Geological Survey of India, Professor of Geology and Mineralogy, Manchester University, and Rector, Imperial College of Science and Technology, South Kensington, England.

Professor *B. Trumpy* of Bergen, Norway, came to the United States in May, 1947, to visit laboratories and make personal contacts. Besides being Professor of Physics, he is Director of Bergens Museum and Det Geofysiske Institutt. These two institutes are to be given university status under the name of Bergens Universitet. A separate building will house a 47 MEV betatron and a 1.5 MEV electrostatic generator. Prof. *Trumpy* is also responsible for the geomagnetic work now being done in Norway.

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DIFFERENTIAL-PENETRATION THEORY

By T. L. Eckersley

There is a good deal of evidence for the existence of differential penetration. It explains a number of things which are otherwise difficult to account for.

An attempt is made, in this paper, to develop this basic idea of differential penetration. It is this:

We assume a neutral cloud of electrons and positive particles, of dimensions large compared with the Earth, coming in to the Earth, probably from the Sun, possibly from neutral clouds in space.

There is a difference in the free path of the heavy particles, positively charged, and the electrons, negatively charged. The electrons have a very much shorter free path than the positive particles, and the result is that if the cloud penetrates the ionosphere, the electrons are caught up at a higher level than the positive particles.

An illustration of this is shown in the figure in *Nature* [**150**, 177 (Aug. 8, 1942)], where, during a period $21^h\ 30^m$-$22^h\ 05^m$, the positives ionize the *E*-layer, and the *F*-layer is blanketed.

The *F*-layer is generally so lacking in density that it reflects nothing, and just before the *E*-layer is ionized, the *F*-layer's apparent height increases rapidly, as if it were approaching its critical frequency.

The result of this differential penetration will be a vertical electric field which, together with the Earth's magnetic field, produces a drift of all particles, independent of their charge. This drift, at times, can produce magnetic storms.

We have to account for the fact that the positive particles increase the ionization in the *E*-layer, while the negative particles reduce the

ionization in the F-layer. This follows from the theory of the movement of charged particles in the layer.

In the E-layer there is very little drift, because of the large collision frequency. In the F-layer there is a big drift, which reduces the number of electrons to a very small value. Thus the F-layer density is reduced and the E-layer density is increased.

Both the drift and the time-integral of the velocity are proportional in the two layers to the time between collisions. Thus in the F-layer they are nearly 100 times greater than in the E-layer.

We have to determine, mathematically, the movement of electrified particles in the cross fields. The fields are composed of a vertical electric force and a magnetic force due to the Earth. The mathematics follows.

We start with the motion of an electron in the F-layer, and the general equation is

$$-m_0\left\{\frac{d^2x_\mu}{ds^2} + \{\alpha\beta,\,\mu\}\,\frac{dx_\alpha}{ds}\,\frac{dx_\beta}{ds}\right\} = F^\mu_\nu J^\nu\,*$$

where α and β are here suffixes.

J^ν is the current-vector

$$\rho\,\frac{dx}{dt},\qquad \rho\,\frac{dy}{dt},\qquad \rho\,\frac{dz}{dt},\qquad \rho c$$

and F^μ_ν is the tensor

$$\begin{matrix} 0 & -\gamma & \beta & X \\ \gamma & 0 & -\alpha & Y \\ -\beta & \alpha & 0 & Z \\ X & -Y & -Z & 0 \end{matrix}$$

where X, Y, Z and α, β, γ are the components of the electric and magnetic fields, respectively.

The movement of the electrons is in a flat Galilean space; but since the geodesic between the receiver and transmitter on the Earth is different from that in free space, we must, in principle, retain the curly bracket $\{\alpha\beta\mu\}$ though in practice this is absolutely negligible. It represents, partly, a force equal and opposite to the centrifugal force, which is v^2/r, and is required to keep the radius constant. We can show that it is between 10^8 and 10^9 times as small as the main term.

*Compare Eddington, "Mathematical Theory of Relativity," pp. 59-61 and 181.

We can neglect this effect, and obtain the motion of the electron in a flat space tangent to the sphere. It is a quasi-stationary value.

When the curly bracket is neglected, the equations become

$$m\frac{d^2z}{dt^2} = -eZ + (0 - v_y e\alpha)$$

$$m\frac{d^2y}{dt^2} = 0 + (v_z e\alpha - v_x e\gamma)$$

$$m\frac{d^2x}{dt^2} = 0 + (v_y e\gamma - 0)$$

$$X = Y = 0, \beta = 0 \text{ approximately}$$

The energy integral is

$$\frac{d}{dt}\frac{m}{2}(v_x^2 + v_y^2 + v_z^2) = -eZv_z$$

also

$$m\frac{d^2v_y}{dt^2} = e\left(\frac{dv_z}{dt}\alpha - \frac{dv_x}{dt}\gamma\right)$$

Now

$$m\frac{dv_z}{dt} = -eZ - v_y e\alpha$$

so that

$$m\frac{d^2v_y}{dt^2} = e\left(-\frac{e}{m}Z\alpha - v_y\frac{e}{m}\alpha^2 - \frac{e}{m}v_y\gamma^2\right)$$

that is

$$\frac{d^2v_y}{dt^2} + \frac{e^2}{m^2}v_yH^2 = -\frac{e^2}{m^2}Z\alpha$$

We have to determine the solution of this differential equation under suitable initial conditions. On inspection, it is obvious that v_y is periodic with a period $\tau = 2\pi m/eH$ or a frequency $\nu = eH/2\pi m$, which is the gyro-frequency.

The differential equation can be put in the form.

$$\frac{d^2v_y}{dt^2} + \eta^2v_y = A$$

where $A = -e^2Z\alpha/m^2$ and $\eta^2 = e^2H^2/m^2$, so that v_y can be put in the general form

$$v_y = \frac{A}{\eta^2} + \frac{Ce^{-i\eta t}}{-2i\eta} + De^{i\beta t}$$

The constant drift-velocity $\bar{v}_y$ is A/η^2, that is

$$-\frac{e^2Z\alpha}{m^2}\bigg/\frac{e^2}{m^2}H^2 = -\frac{Z\alpha}{H^2}$$

and is independent of e and m.

We have

$$y = \frac{A}{\eta^2}t - \frac{C}{2\eta^2}e^{-i\eta t} + \frac{D}{i\eta}e^{i\eta t}$$

and $v_y = 0$ when $t = 0$, so that

$$\frac{C}{2i\eta^2} = -\frac{D}{\eta} \qquad \text{that is} \qquad \frac{C}{2i\eta} = D$$

and

$$v_y = \frac{A}{\eta^2} + 2D\cos\eta t$$

When $t = 0$, $v_y = 0$, $0 = A/\eta^2 + 2D$, or $D = -A/2\eta^2 = Z\alpha/2H^2$ and

$$v_y = -\frac{Z\alpha}{H^2}(1 - \cos\eta t)$$

We can now obtain v_z and v_x.

$$m\frac{dv_z}{dt} = -eZ - \dot{v}_y e\alpha$$

$$= -eZ + \frac{Ze\alpha^2}{H^2}(1 - \cos\eta t)$$

or

$$m\frac{dv_z}{dt} = -eZ\left(1 - \frac{\alpha^2}{H^2}\right) - e\frac{Z\alpha^2}{H^2}\cos\eta t$$

Integrating

$$mv_z = -eZ\frac{\gamma^2}{H^2}t - e\frac{Z\alpha^2}{H^2_\eta}\sin\eta t$$

$$v_z = -\frac{e}{m} Z \frac{\gamma^2}{H^2} t - \frac{e}{m} \frac{Z\alpha^2}{H_\eta^2} \sin \eta t$$

$$= -\frac{e}{m} Z \frac{\gamma^2}{H^2} t - \frac{\alpha}{H} \left(\frac{Z\alpha}{H^2} \sin \eta t\right)$$

Also

$$m \frac{dv_x}{dt} = ev_y\gamma = -eZ \frac{\gamma\alpha}{H^2} (1 - \cos \eta t)$$

$$v_x = -\frac{e}{m} Z \frac{\alpha\gamma}{H^2} t + \frac{e}{m} Z \frac{\alpha\gamma}{H_\eta^2} \sin \eta t$$

$$= -\frac{eZ\alpha\gamma}{mH^2} t + Z \frac{\alpha\gamma}{H^3} \sin \eta t$$

$$= -\frac{eZ}{m} \frac{\alpha\gamma}{H^2} t + \frac{\gamma}{H} \bar{v}_y \sin \eta t$$

Collecting our results, we have

$$v_x = -\frac{eZ}{m} \frac{\alpha\gamma}{H^2} t + \frac{\gamma}{H} \bar{v}_y \sin \eta t$$

$$v_y = -\bar{v}_y(1 - \cos \eta t)$$

$$v_z = \frac{eZ}{m} \frac{\gamma^2}{H^2} t - \frac{\alpha}{H} \bar{v}_y \sin \eta t$$

If the x-axis is chosen to point north, then relative to our axes we have:

(1) A motion with constant velocity $\bar{v}_y$ westerly

(2) A constant acceleration downwards of $(eZ/m)\ (\gamma^2/H^2)$

(3) A constant acceleration northwards $(eZ/m)\ (\alpha\gamma/H^2)$

and purely periodic movements given by

$$v_x' = \frac{\gamma}{H} \bar{v}_y \sin \eta t$$

$$v_y' = -\bar{v}_y \cos \eta t$$

$$v_z' = -\frac{\alpha}{H} v_y \sin \eta t$$

Thus the electrons have an accelerated spiral down the lines of magnetic force, together with a westward drift. The positive ions have an accelerated spiral up the lines of magnetic force with the same westward drift.

We learn from this that all the particles in the F-layer have a westward drift, at least on the magnetic meridian, at midday, with the result that all the electrons are swept away, and no more enter. The ionization in the F-layer may therefore become very small. This accounts for the fact that in all these types of magnetic storm the ionization is reduced in the F-layer.

It has been suggested that the ionization might be reduced by heating the layer, but this would require such enormous expansion of the atmosphere that I think it is quite out of the question.

The formula $\bar{v}_y = -Z\alpha/H^2$ shows that all the particles are drifting. The electrons are not pulled back by the positives because the positives move just as much as the electrons. There is, however, an excess of electrons which will produce a current in the F-layer and a magnetic storm.

This has been discussed in a letter to *Nature* [**150**, 177 (Aug. 8, 1942)].

It is shown in the mathematics in this paper that there is a downward motion as well as a horizontal drift-motion. This downward motion is really due to the vertical electric field, and is proportional to the square of the time between collisions. The drift-motion is proportional to the linear function of the time, so that the horizontal drift can always be made large compared with the downward motion if the time between collisions τ is made small enough or the cloud velocity is great enough. In general, both these conditions are present.

We have a difficulty in determining the exact motion of the electrons and other particles in the F-layer, because we do not know their initial masses or speeds in the neutral cloud. We may assume that the velocity is of the order of 10^8 cm per second, because it takes a cloud something like 20 hours to get from the Sun to the Earth. We do not know the initial density of the cloud, but this is probably small, because it does not affect spectroscopy much.

These effects which I have been discussing are associated with magnetic storms. There probably is, as well, a diurnal effect which is not associated with magnetic storms. We assume that the F-layer is partly ionized by neutral clouds from the Sun, with the result that it may produce a diurnal variation in the Earth's magnetic field, and currents in the F-layer. These will have the effect of modifying the normal diurnal F-layer density, and producing anomalous effects in the ionization of the F-layer. The anomalous effects depend upon the drift of electrons, and are therefore related to the Earth's magnetic field.

Anomalous effects—If the $F2$-layer were wholly ionized by the Sun's

ultra-violet radiation, then the diurnal variation of the electron-density over an eastern station should be the same as that over a western station of similar latitude. Thus, for example, the midday density at Delhi should be the same as the midday density at Baton Rouge, because they are nearly the same latitude. The densities are not the same. The eastern station, Delhi, has a much higher density than the western station, Baton Rouge. The same occurs with Tokio and Washington. There is no doubt that the eastern northern stations have greater density than the western northern stations.

This is usually known as the "anomalous longitude effect." Appleton has discussed it in a letter to *Nature* of May 25, 1946, and has shown that this anomalous effect is confined to the $F2$-layer, and can be removed if the density of the $F2$-layer is plotted as a function of the Earth's magnetic dip, or—what is the same thing—of the geomagnetic latitude. It is a very happy way of expressing the density of the layer as a function of the geomagnetic latitude, and this forms an excellent description.

There is another anomaly. It is that which occurs at or near the Earth's geomagnetic equator—at Huancayo, for example. We can see here that there is an evening concentration of the electron-density which cannot be explained as an effect due to ultra-violet ionization. The fact that the anomalies disappear when plotted as a function of the geomagnetic latitude suggests that the effects are due to the Earth's magnetic field.

All these results can be explained as an effect of differential penetration. We can examine the effects most simply by referring to a figure of the Earth at the equinox (Fig. 1). Here it is shown as a neutral cloud comes in from the Sun. At sunrise and sunset, the electric force due to differential penetration is horizontal. At midday it is nearly vertical. At sunset the horizontal electric force and the horizontal magnetic field, which are at right-angles, produce vertical drifts, upward at sunrise and downward at sunset.

The vertical magnetic field in the meridian and the horizontal electric force at right-angles to the meridian produce a drift towards the magnetic equator which causes a concentration of electrons at sunset. Those of the electrons which are north of the equator are drifted southward, and those which are south of the equator are drifted northward. This is because of the reversal of the vertical magnetic field at the equator, together with a constant electric force.

When, at sunrise, the vertical magnetic field is reversed in space, the electric field remains the same. The horizontal magnetic field is not reversed, and that, with the horizontal electric force, produces, in space, the same drift as before, that is, downwards at sunset and upwards at sunrise.

The result is that at sunrise there is a reduction of electrons and at

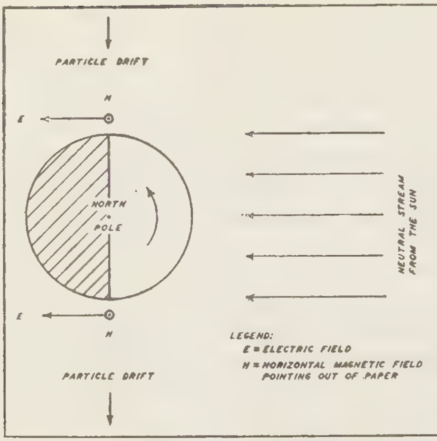
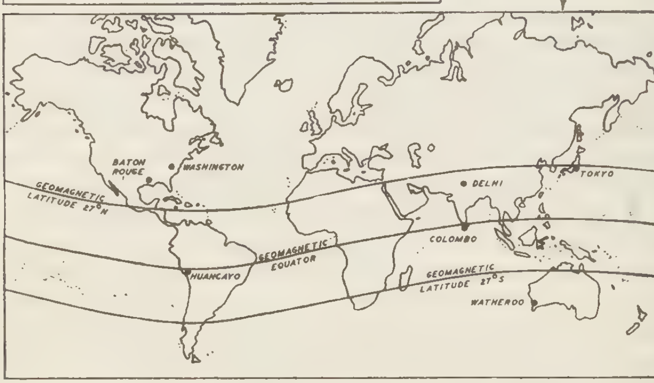


FIG. 1

FIG. 2—WORLD CHART SHOWING GEOMAGNETIC EQUATOR LATITUDE 27° NORTH AND LATITUDE 27° SOUTH



sunset an increase of electrons. This accounts for the anomalous concentration of electrons at and near the magnetic equator in the evening, and therefore explains the second type of anomalous effect. It will affect the $F2$-layer mainly, because the drifts in the E-layer are so small.

We have now to explain the anomalous longitude effect in the $F2$-layer, that is, "east and west effect." Perhaps the best way of understanding it will be to look at the map, Figure 2, which indicates that, apart from a shallow minimum of about 27 per cent at the magnetic equator, the density increases with proximity to the magnetic equator. There is a maximum density at about 25° to 30° north and south of it. The full lines show where the density at midday is a maximum. They run close to, and parallel to, the magnetic equator. Tokio and Delhi are nearly on a line, but Washington and Baton Rouge are far north of it. Thus

the maximum density at Tokio and Delhi is much greater than that at Washington and Baton Rouge.

Watheroo, in Western Australia, is very far from the magnetic equator, and though nearly as far east as Tokio, does not, in virtue of this, show the anomalous longitude effect.

The effects here are therefore due to particle ionization, which, with the drift-effect, is much greater near the magnetic equator than elsewhere.

These particulars are obtained from the experimental results published by Appleton in the letter to *Nature* already referred to.

It is now clear why there is an anomalous longitude effect.

The shape of Figure 2 in Appleton's letter, can easily be explained in terms of the differential-penetration theory (or drift-theory). Thus the afternoon drift, which depends upon the gradient of the vertical magnetic force, is greatest near the magnetic equator. This is also true of the mid-day drift, probably caused by diffusion. But the density does not depend upon the drift alone. It depends also upon the number of particles that there are to drift. The particles, or electrons, are dragged into polar and auroral regions by the Earth's magnetic field, and they depend upon the sine of the magnetic latitude. On the other hand, the drift, which is a maximum at the magnetic equator, depends upon the cosine of the magnetic latitude. The two together therefore depend on the product of the sine and cosine, which has a maximum at 45° from the magnetic equator.

Thus the drift-effect has a maximum somewhere near 45° from the magnetic equator, and the ultra-violet ionization probably has a maximum at the equator. The result of the two together is that they have a maximum somewhere between 0° and 45° from the magnetic equator. This has, in fact, been found some 20° to 30° from it.

Ceylon effect—It has been observed in Ceylon that when the density is small enough we may see an extra layer above the $F2$-layer. We may call this the G-layer. In the morning it travels upwards. This may be due to particle ionization.

The G-layer could be explained as a particle ionization which, on account of differential penetration, has a drift upwards in the morning.

The Ceylon effect is not at variance with the explanation already given. On the contrary, it confirms it.

Thus we have, in the "Differential-penetration theory," an explanation of nearly all the major anomalous effects.

Types of magnetic storm—There appear to be two types of magnetic storm. One is the "Differential-penetration" type and the other is what may be called the "Ring" type. This latter is caused by a movement of charged particles beyond the $F2$-layer. There is experimental evidence of this. It is given in a paper by Berkner and Seaton in *Terrestrial Magnetism and Atmospheric Electricity* [45, 393-418 (1940)], and is shown in Figure

13 of that paper. In this it appears that there is a magnetic disturbance before $15^h\ 44^m.8$, and that the ionic disturbance only takes place after this. Therefore there is a magnetic disturbance before the ionosphere is affected, and this cannot be associated with differential penetration.

This can be explained easily enough. We can assume that in this case there is a slow-moving neutral cloud which does not penetrate the ionosphere. This cloud is acted on by the Earth's magnetic field, which produces a cleft in the cloud and drives the particles in a ring stream round the Earth.

This is the type of storm described and explained in detail by Chapman and Bartels in their book "Geomagnetism" [Chapter 25, "Theories of magnetic storms and aurorae", p. 850 (1940)].

These two types of magnetic storm may occur together and produce very complicated results which are not easy to explain, but fortunately we have a case here [Fig. 13 of article by Berkner and Seaton] where the two are independent.

Weatheroak, Danbury, Essex, England, May, 1947

POLAR RADIO DISTURBANCES DURING MAGNETIC BAYS*

By H. W. Wells

Comparison of ionospheric and magnetic records at College Observatory, College, Alaska, shows very definite ionospheric effects during magnetic bays. High absorption producing partial to complete radio blackouts was coincident with each of 69 significant magnetic bays which were examined for the period January to September, 1942. The radio absorption is limited to duration of the magnetic bay, thereby establishing a direct relationship which is unusual in magnetic-ionospheric investigations.

Strong absorption of radio waves associated with complete disappearance of all signals is often encountered in the polar regions. This condition is known to become more pronounced during periods of magnetic and ionospheric disturbance. Continuous operation of the Observatory at College, Alaska, near the zone of maximum auroral and magnetic activity, has revealed important information concerning ionospheric characteristics and radio wave-propagation in polar regions. College Observatory was established in 1941 by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in cooperation with the University of Alaska. It was operated by the Carnegie Institution of Washington until 1946 with support of the National Defense Research Committee, Navy Department, and the Wave Propagation Committee of the Joint Communications Board. Since 1946 operation was continued by the University of Alaska under contract with the Central Radio Propagation Laboratory of the National Bureau of Standards. The general program includes continuous ionospheric recordings over a wide range of frequencies, signal-intensity recordings on high-frequency broadcasting stations, magnetic observations, auroral studies, and special direction-finder operations.

Polar radio "blackouts" are similar *in effect*—but not in cause—to the "sudden ionospheric disturbances" or radio fade-outs which occasionally are observed, especially in lower latitudes, for short intervals *during daylight only*. The fade-out has been unquestionably connected with solar flares through the work of Dellinger and others. The generally accepted explanation of the solar-flare fade-out is that ultra-violet radiation from the flare is absorbed selectively and produces *intense ionization* below the normal *E*-layer of the ionosphere in regions of relatively high molecular density. Radio-frequency energy in the part of the spectrum commonly used for long-distance communications is dissipated for the duration of the ionizing radiation. In addition, a small but characteristic magnetic pulsation has been identified.

*Prepared December 31, 1942, as Special Report No. 1 for limited distribution to sponsoring organizations; revised April 28, 1947.

Ionospheric recordings at College, Alaska, have indicated frequent occurrence of polar radio blackouts (as distinguished from fade-outs) even during mild magnetic disturbances. Such disturbances constitute a serious handicap to radio communications which pass near the auroral zones. These blackouts last from several hours to several days depending on the extent and duration of the magnetic disturbance.

A special type of polar radio blackout is found to occur during magnetic bays. The magnetic bays [see 1 and 2 of "References" at end of paper] are typical disturbances of short duration which are preceded and followed by generally undisturbed magnetic conditions. The bays are very pronounced near the auroral zones although their magnetic effects extend to equatorial regions.

Two separate illustrations of magnetic bays and coincident polar radio

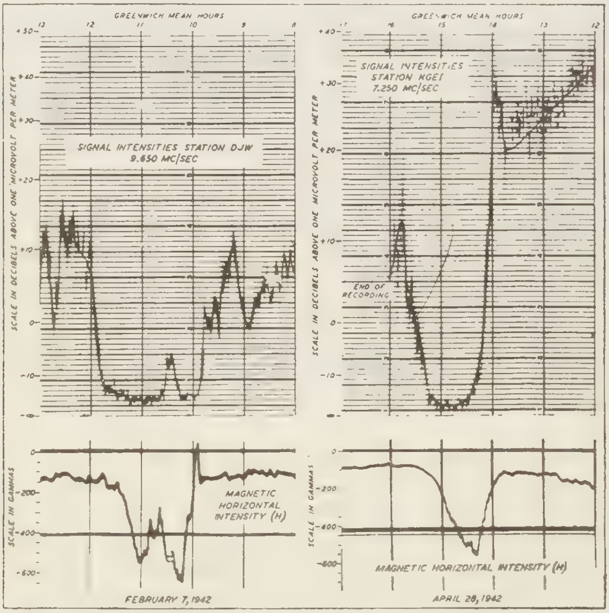


FIG. 1—HIGH ABSORPTION AT COLLEGE, ALASKA, DURING MAGNETIC BAYS

blackouts are presented in Figure 1. (Note that time-scale progresses from right to left.) The magnetic disturbance of February 7, 1942, started at $09^h\ 50^m$ GMT. At the same time, signals from DJW (Germany) on 9.650 Mc/sec dropped out. The magnetic bay lasted until about $11^h\ 45^m$ following which recordings were normal. Signals from DJW began to recover at $11^h\ 45^m$ and reached normal about $12^h\ 00^m$.

The magnetic bay of April 28, 1942, started about $13^h\ 50^m$, and lasted until $15^h\ 40^m$. Signals from KGEI (San Francisco) on 7.250 Mc/sec tempo-

rarily increased from $13^h\ 50^m$ until $14^h\ 00^m$ and then dropped out very suddenly. The signals began to recover at $15^h\ 15^m$ and reached normal at $15^h\ 45^m$.

Ionospheric characteristics at College Observatory during the magnetic bays of Figure 1 are reproduced in Figure 2 for February 7, 1942, and Figure 3 for April 28, 1942. Records consist of a series of frequency-sweeps every 15 minutes over a range, 16.0 to 0.516 Mc/sec, with automatically recorded heights of signals returned from the ionosphere.

The records of February 7, 1942 (Fig. 2) show sporadic E-region ionization from $08^h\ 00^m$ to $10^h\ 00^m$. The first reflections are unchanging over a wide frequency-range, coming from the E-region at 100 km. Several multiple echoes above the E-level are produced by signals which have traveled back and forth several times between E-layer and Earth. The number of multiple echoes provides an indication of relative absorption experienced by the exploring radio signals. After $10^h\ 00^m$ (coincident with development of the magnetic bay) the ionospheric echoes were strongly absorbed. Occasional spotty echoes were recorded but all multiple echoes disappeared. After $11^h\ 30^m$, an improvement was noted and the frequency-sweep at $11^h\ 45^m$ was practically normal with the same type of sporadic E-ionization. Subsequently, the sporadic E gradually disappeared, revealing the higher $F2$-region.

The ionospheric records of April 28, 1942 (Fig. 3) show complete absorption of signals during the magnetic bay illustrated in Figure 1 which started at $13^h\ 50^m$ and recovered at $15^h\ 40^m$. The effect is most pronounced between $14^h\ 00^m$ and $15^h\ 15^m$. Preceding the radio blackout sporadic E-region ionization was present, but following the disturbance the ionosphere appeared to be normal.

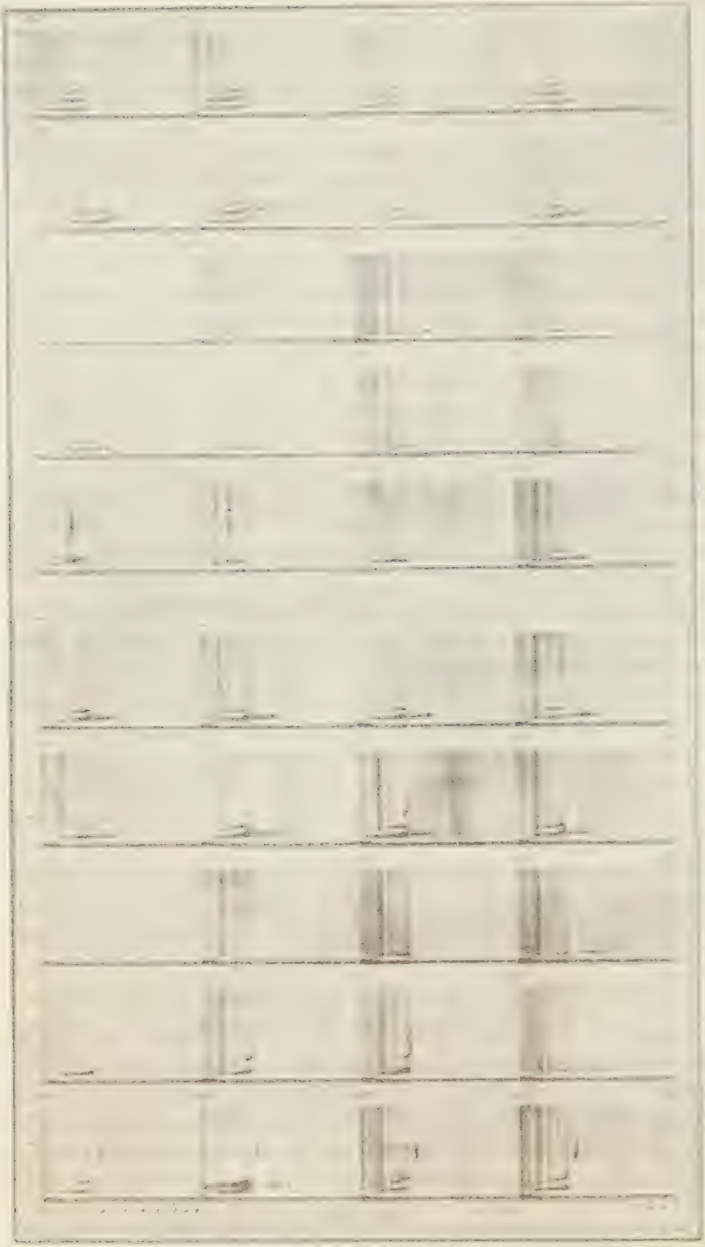
During the period January to September, 1942, 69 significant magnetic bays were examined. This is an average of nearly eight per month. As mentioned above, in every case ionospheric absorption was indicated by partial to complete disappearance of radio-frequency signals propagated through the ionosphere.

The monthly distribution of bays, during January to September, 1942, used for this investigation is as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Total
5	4	9	8	6	5	11	10	11	69

These disturbances occur most frequently at College between 10^h and 16^h GMT with a maximum at 12^h GMT. Other periods of the day are relatively free from this effect. The above distribution is in general agreement with the reports of Lubiger [3] who found more frequent occurrence of bays during the equinoctial periods.

An interesting feature of such disturbances is their pronounced recurrence-tendencies at intervals of about one day. This is an established



phenomenon, originally reported by Balfour Stewart in 1882 [4]. Magnetic bays frequently run in series of two to five days. The time-interval between recurring bays is close to 24 hours, and the relative intensity decreases as the series continues. Figure 4 illustrates a three-day recurrence, January 2, 3, and 4, 1942, at College, Alaska.

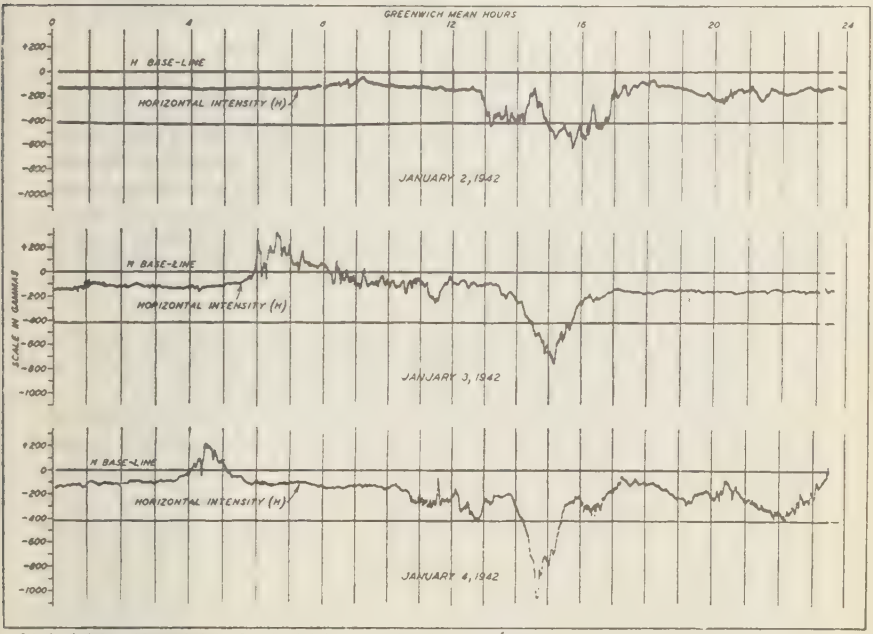


FIG. 4—TYPICAL RECURRENCES OF MAGNETIC BAYS AT COLLEGE, ALASKA (THESE BAYS NORMALLY COINCIDE WITH RADIO ABSORPTION AND BLACKOUTS)

This recurrence-tendency of bays is an especially interesting characteristic for which a sound physical explanation is difficult. The effect, however, offers an opportunity for practical application to short-term forecasting of polar radio blackouts approximately one day after an observation of a coincident magnetic bay and radio blackout.

Both the magnetic and radio effects can be explained through development of intense ionization in the ionosphere below the normal *E*-layer. In contrast with the fade-out as mentioned above, the blackout appears to be produced directly or indirectly by impact or bombardment of the atmosphere by rapidly moving corpuscles or particles which travel with velocities slower than that of light. Intense ionization in atmospheric regions of relatively high molecular density causes absorption of radio signals entering that region. The same ionization, or increased conductivity, permits the flow of electrical currents which react upon the Earth's magnetic field as bays and other disturbances.

Attention is invited to the fact that the same basic explanation of the sunlight radio fade-out, namely, absorption due to intense ionization in the lower ionosphere, is generally accepted. However, the ionization producing the sunlight fade-out is caused by radiation from a solar flare observed simultaneously with the fade-out, while the ionization producing the polar blackouts, so prevalent during all magnetic disturbances, undoubtedly results from particle bombardment (or equivalent) which appears to have a lag of one day or more from Sun to Earth.

The very frequent occurrence of sporadic E-region ionization in the high latitudes likewise indicates particle bombardment as the ionizing agent. There is reason to assume a close relationship between polar radio blackouts and sporadic-E ionization since both effects result from intense ionization and both seem to be produced by corpuscular bombardment. The only fundamental difference may be in the *actual* height at which this ionization is produced. Measurements show sporadic-E ionization to occur most frequently between 100 and 120 km. It is estimated that intense ionization at 80 km or lower will result in radio absorption.

A significant deduction from these observations of importance to theoretical analysis of the Earth's magnetic field is that current-systems in arctic regions probably are concentrated at levels below 80 km.

The analyses also permit an estimate of the area of radio absorption during a magnetic bay. The simultaneous occurrence of absorption in the ionosphere at College, Alaska, with absorption at a distant point in the ionosphere (as disclosed by signal-intensity recordings) reveals two widely separated areas influenced by the same bay. Although the actual distance between the two absorption areas is dependent on mode of propagation of the oblique-incidence signal, a separation of 500 miles would be a reasonable figure. Since the effect extends beyond the two observed points, it may be assumed that the absorption area is appreciably more than 500 miles in extent. The area of maximum absorption is probably outlined by the intense portion of the current-system in the ionosphere required to produce the magnetic effect. One may therefore assume that the absorption extends in a band several hundred miles wide along the night portion of the auroral zone.

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THE IONOSPHERE AS A MEASURE OF SOLAR ACTIVITY

By M. Lindeman Phillips

Abstract—Critical frequencies of all regular ionospheric layers vary diurnally, seasonally, with geographic latitude and longitude, and with solar activity so that, for any location and any season

$$f^0 = G(t) + H(t)S$$

where f^0 is the critical frequency, G and H are functions of (t), the time of day, and S is the sunspot-number. For locations where such ionospheric trends are well established, observations of critical frequency may be used to determine an ionospheric "sunspot-number". If values of $F2$-layer critical frequency for hours near local noon are used, since these generally have the most pronounced variation with solar activity, the ionospheric "sunspot-number" obtained is considerably closer to its running-average value than are ordinary sunspot-numbers to their running averages. In addition, this measure is practically independent of varying atmospheric conditions and personal variation among observers, and therefore probably presents a more precise index of solar activity.

(I) *Introduction: Parallelism of ionospheric and solar phenomena*

Correlation between the long-term variations of critical frequencies for the various layers of the ionosphere and those of many other solar and terrestrial phenomena which vary causally with solar activity has been known for some time [see 1, 2 of "References" at end of paper], their co-variation with sunspot-number being of considerable practical importance in the prediction of usable radio frequencies [3, 4].

Comparison of the data in Figures 1, 2, and 3, where noon critical frequencies for the $F2$-, $F1$-, and E- layers of the ionosphere, as well as midnight values of the $F2$-layer, are presented together with their 12-month running averages, for Washington (D. C.), Huancayo (Peru), and Watheroo (Western Australia) with the sunspot-data presented in Figure 4 shows that:

(*a*) *There exists long-term parallelism between the 12-month running averages of the critical frequencies and the sunspot-number, although there is no obvious short-term parallelism.*

Lack of accurate short-period parallelism may result for several reasons. Since variations in sunspot-number and the critical frequencies are co-causal, short-term variations in either may be to some extent the result of independent statistical variation, or of variable factors other than solar activity. [Besides, the 12-month running averages, which serve to remove the seasonal variations of critical frequencies as well as smooth the time-trends may obscure any short-term fluctuations.]

(*b*) *The relative change of ionospheric critical frequency with sunspot-number varies with layer, geographical location, and time of day.*

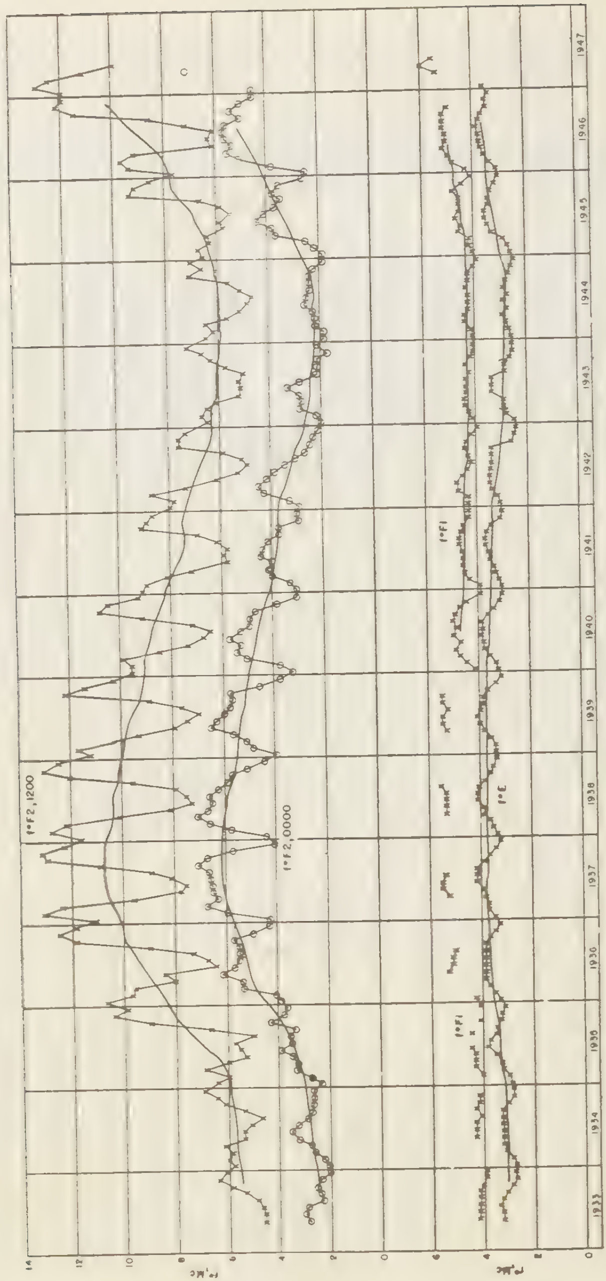

Fig. 1 TIME VARIATION OF NOON f°E, f°F1, f°F2, AND MIDNIGHT f°F2, AT WASHINGTON, D.C

In general, the amount of this variation increases with the magnitude of the quantity under consideration.

(c) *Magnitude of the seasonal variation generally varies with the quantity under consideration.*

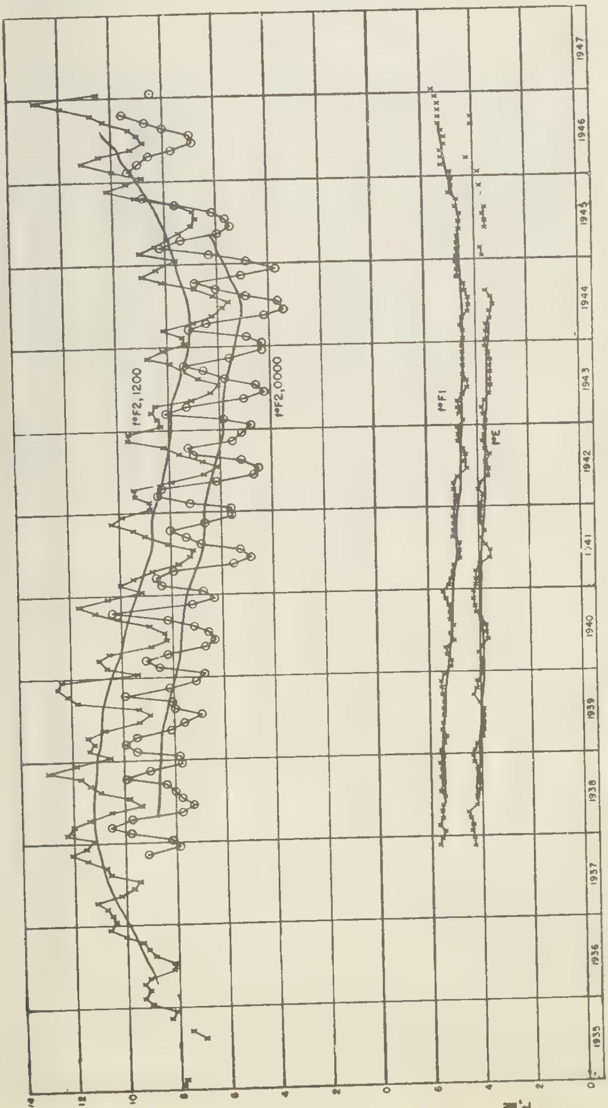

Fig 2. TIME VARIATION OF NOON f°E, f°FI, f°F2, AND MIDNIGHT f°F2, AT HUANCAYO, PERU

(d) The 12-month running-average curves of critical frequency are smoother than those for sunspot-number.

This suggests that measurements of ionospheric critical frequencies, being fairly continuous, may furnish a preferable index of solar activity.

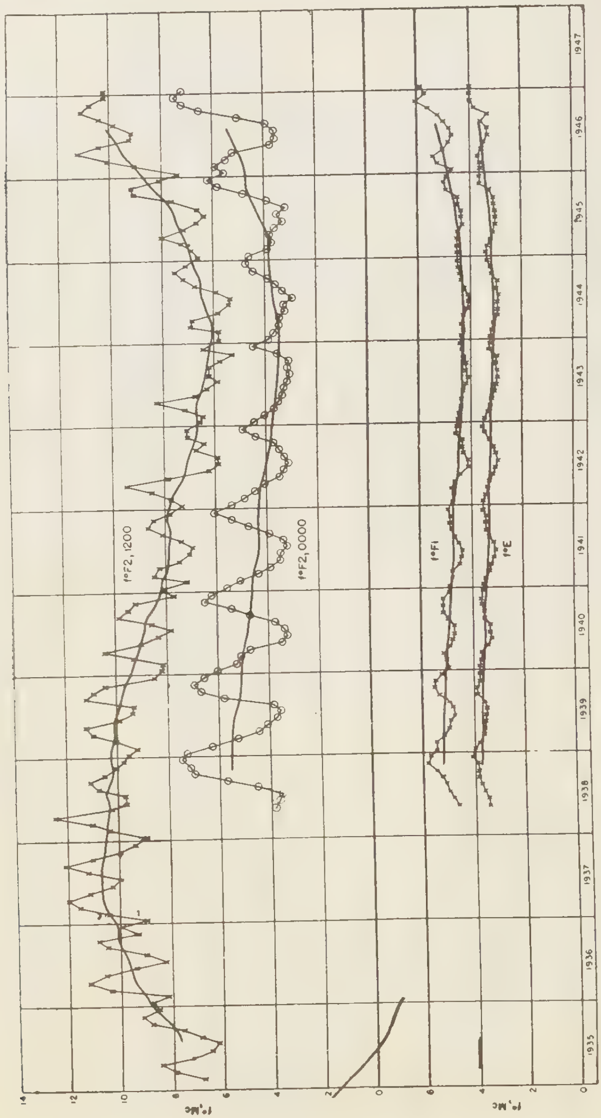

Fig. 3 TIME VARIATION OF NOON f°E, f°F1, f°F2, AND MIDNIGHT f°F2, AT WATHEROO, W AUSTRALIA

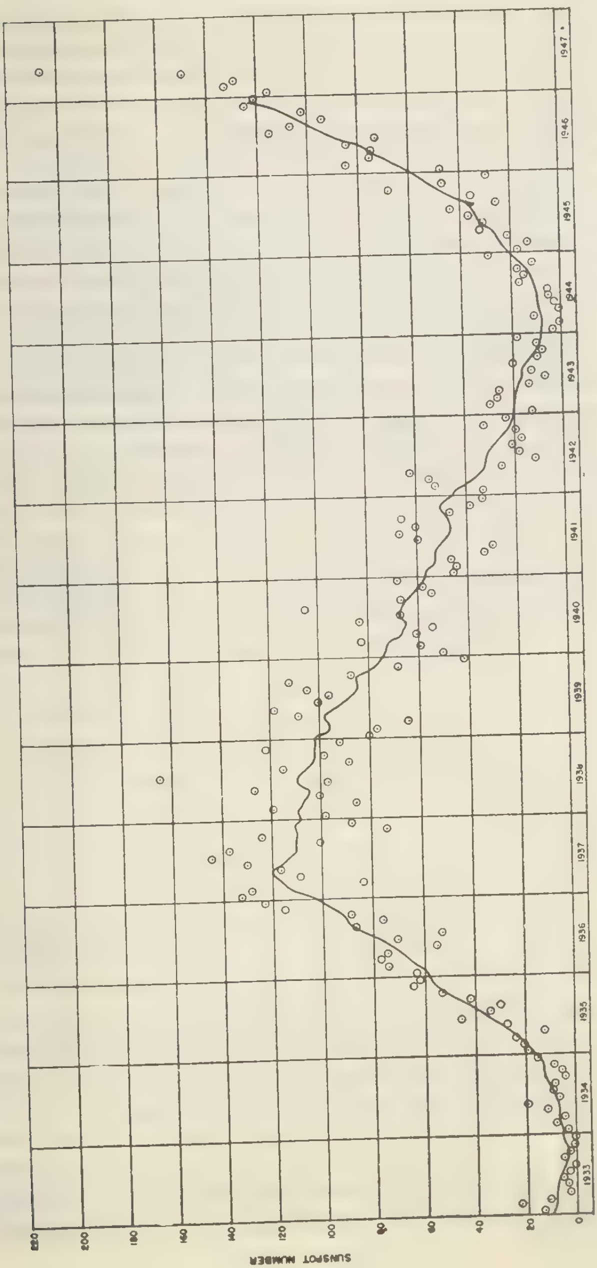

Fig. 4. VARIATION OF ZURICH SUNSPOT NUMBER

Individual measurements of critical frequency are rather precise, given to the nearest 0.1 Mc, entail far less personal judgment among observers, and are not impaired by variable atmospheric observing conditions as are measurements of sunspot-number. Moreover, day-to-day variability is such that a fair current estimate may be obtained from only a few days' observations.

The examples of critical-frequency data presented here are those for which the longest time-series are available. The general characteristics noted above in their variations apply to all layers, at all hours of the day, and for all of about 60 ionosphere stations at widely different geographical locations.

(II) *Relation between critical frequencies and sunspot-number*

The relation between ionospheric critical frequency and sunspot-number is approximately linear, for all layers, all times of day, and all geographical locations. That the relation is generally as close as that exhibited in Figure 5, which is a typical case, is remarkable when one

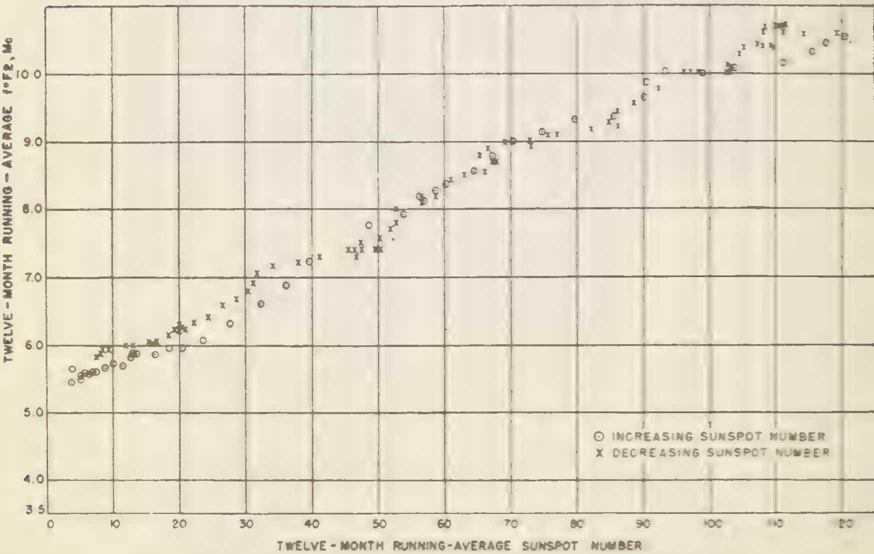

Fig. 5 VARIATION OF TWELVE-MONTH RUNNING-AVERAGE f°F2, 1200, AT WASHINGTON, D. C., WITH TWELVE-MONTH RUNNING-AVERAGE SUNSPOT NUMBER

considers the very arbitrary nature of the relative sunspot-number (the sum of the total sunspot-count plus ten times the number of spot-groups, all multiplied by a constant characteristic of observatory apparatus and

seeing conditions) chosen by R. Wolf nearly a century ago as an index of solar activity. It is of interest that the linearity of this relationship parallels the linear relationship found by E. Pettit [5] between solar emission of ultra-violet light and the number of sunspot-groups.

The slopes and zero-intercepts of such curves are different for different times and places. All indicate that the zero-value of solar activity as measured by sunspot-numbers lies far above that derived from ionospheric critical frequencies.

The monthly index (or ratio of monthly-average critical frequency to the 12-month running average centered at that month) is nearly constant, although for some times and places it exhibits a slight variation with sunspot-number. Thus plots of critical frequencies, for any given month, against sunspot-number, are likewise approximately linear.

For any ionospheric layer, at any time or place, the variation of critical frequency may therefore be represented by the expression

$$f^0 = G(t) + H(t)S$$

where f^0 is the critical frequency, S is the smoothed sunspot-number, and G and H are functions of the time of day, t, which are appropriate to the season and location.

This relationship allows great condensation of the information afforded by ionospheric data, since it may be given nomographic representation. The above equation may be given the determinant form

$$\begin{vmatrix} 0 & (L - l_1 f^0) & 1 \\ \delta & l_2 S & 1 \\ M & N & 1 \end{vmatrix} = 0$$

where

$$M = l_1\delta/[l_1 + l_2/H(t)]$$

and

$$N = [L - l_2 l_1 G(t)]/H(t)[l_1 + l_2/H(t)] - Ll_1/[l_1 + l_2/H(t)]$$

The left and middle terms in any row of the determinant indicate corresponding x- and y-coordinates for the nomographic scales, if the origin of coordinates is taken at the lower left-hand corner of the nomogram, and if δ is the width of the nomogram, L the total length of the f^0-scale, and l_1 and l_2 are scale-factors, respectively, for the f^0- and S-scales.

Figures 6, 7, and 8 present nomograms of this type correlating the yearly-average f^0F2 for Washington (D. C.), Huancayo (Peru), and

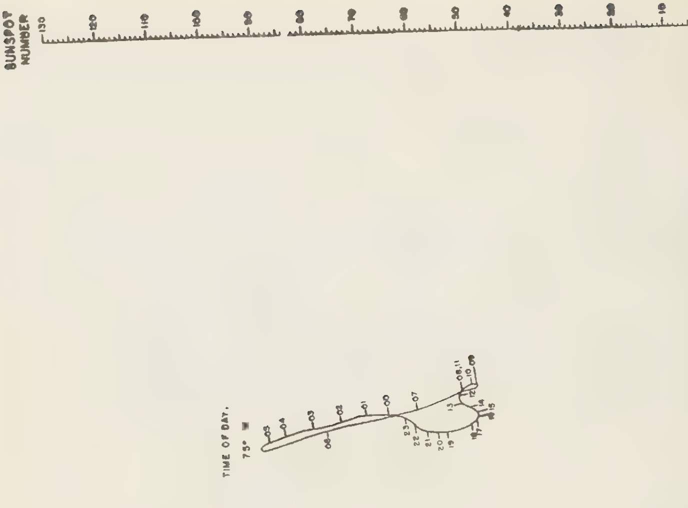

Fig. 7. NOMOGRAM FOR OBTAINING YEARLY AVERAGE f°F2 AT HUANCAYO, PERU

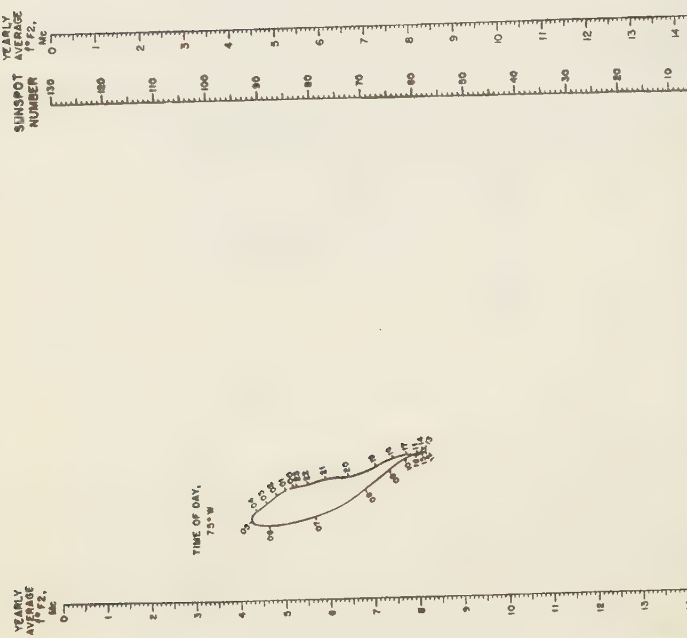

Fig. 6. NOMOGRAM FOR OBTAINING YEARLY AVERAGE f°F2 AT WASHINGTON, D.C

Watheroo (Western Australia) with sunspot-number. A straight line passed through the appropriate value of time of day, on the central (time) scale, intercepts corresponding values of f^0F2 and S on the two vertical

scales. Nomograms of this type have also been constructed for each month, as well as those for the yearly-average values, shown here, and for various ionosphere stations [6].

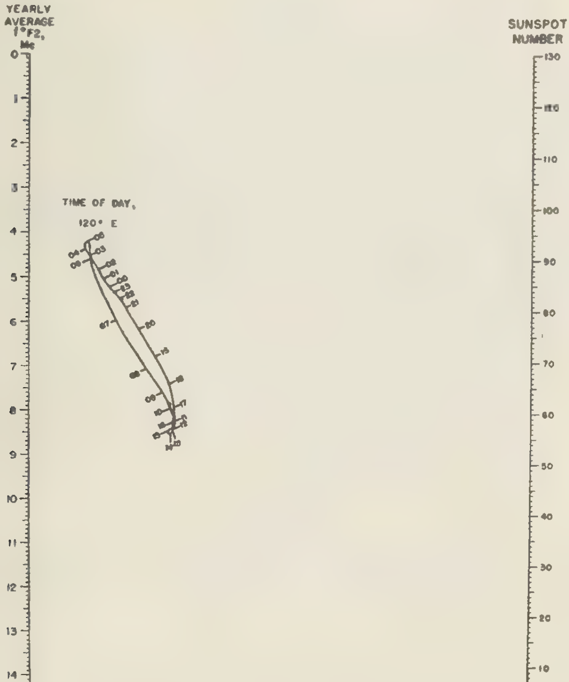

Fig. 8.
NOMOGRAM FOR OBTAINING YEARLY AVERAGE f°F2, AT WATHEROO, W AUSTRALIA

The condensation of the time-scale into a nearly collapsed loop indicates in this case (as well as in other cases not shown here) that the relationship between values of f^0 and S roughly approximates a simple multiplicative time-function, if a "zero"-value on the S-scale is selected at a sufficiently low value. Similar nomograms constructed for correlation of E- and $F1$-layer critical frequencies with sunspot-number have time-scales which are straight lines, indicating such a relationship, where

$$f^0 = F(t)[S + A]$$

Values of A, the negative value of "sunspot-number" corresponding to zero-values of critical frequency are approximately, for the E-layer, 1000, 570, 460, and 400, respectively, for the locations Fairbanks (Alaska),

Washington (D. C.), Huancayo (Peru), and Watheroo (Western Australia). Values of A for the $F1$-layer are, respectively, 470 (rather poorly determined), 770, 360, and 350.

(III) *Application of ionospheric data to measurement of solar activity*

Both the generally good correlation between sunspot-number and critical frequency, and the greater smoothness of critical-frequency variation, suggest that ionospheric frequencies may serve as a more reliable measure of solar activity than sunspot-number.

Maximum reliability in ionospheric measure of solar activity should be attained by the use of data only from stations where a long series of such measurements are available so that solar activity trends are well established, and by the selection of critical frequencies for such use that exhibit maximum solar-activity variation with respect to random day-to-day variation, or sensitivity to abnormal effects, such as those of ionospheric storminess.

It may be readily seen by inspection of the data of Figures 1, 2, and 3 that $F2$-layer critical frequencies vary more with solar activity than do those of other ionospheric layers. Inspection of the nomograms of Figures 6, 7, and 8 shows that $F2$-layer critical frequencies near midday generally vary more with solar activity than do those for other times of day.

The three ionospheric stations at Washington (D. C.), Huancayo (Peru), and Watheroo (Western Australia) possess the longest time-series of such data available for all hours of the day, the first possessing a series of data beginning in 1933.

Values of ionospheric "sunspot-number" were obtained for each of these stations, from the monthly-average f^0F2 at each of the five hours centered on noon, and these values averaged for each month.

These data, obtained by the use of nomograms constructed from monthly trends of f^0F2, are presented in Figure 9, together with their 12-month running-average values. Similar values, not shown here, were obtained by means of nomograms constructed from trends of yearly-average f^0F2, for which a constant monthly index (or ratio of monthly-average to yearly-average f^0F2) was assumed. These latter values closely approximated those derived from monthly trends.

Comparison of the data of Figure 9 with the sunspot-data of Figure 4 shows that the ionospheric "sunspot-numbers" deviate considerably less from their running-average values. The standard deviations of the monthly values from their 12-month running-average value, centered on the month are, respectively, for the relative sunspot-numbers, the ionospheric "sunspot-numbers" derived from yearly-average trends with constant monthly indexes, and the ionospheric "sunspot-numbers" derived from monthly

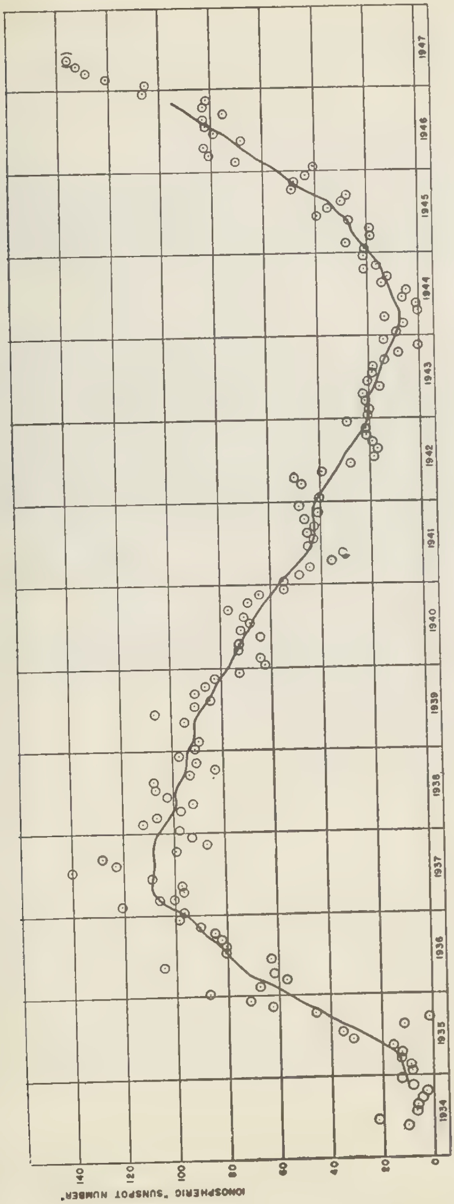

Fig. 9. VARIATION OF IONOSPHERIC SUNSPOT NUMBER* AS DETERMINED BY TREND OF MONTHLY AVERAGE $f°F_2$

trends, 14.9, 10.4, and 9.5. In all cases, the distribution is slightly skewed toward the higher values.

(IV) *Conclusion*

Because of the precision in measurement of ionospheric critical frequencies, their close correlation with solar activity, their ability to measure far lower values of solar activity than those given by sunspot-number, and their consistence, as demonstrated above, their use seems to afford what at present may well be our most precise measure of general solar activity.

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CORONAL RADIATION AND IONOSPHERIC VARIATIONS DURING THE SOLAR ECLIPSE, JULY 9, 1945

By M. Waldmeier

Abstract—From the ionospheric observations made by O. Rydbeck and from the coronal observations made by the author it is deduced that the source of the solar ultra-violet light, producing the *E*-layer, lies in the innermost part of the corona in the regions of highest intensity of the 5303-radiation. Very strong support to this conclusion is given by the fact that in these regions the temperature of the corona reaches its highest values.

Introduction—On different occasions [see 1, 2 of "References" at end of paper] the author suggested that the excess of short-wave ionizing solar radiation, responsible for the ionosphere, might originate in the corona. On the one hand theoretical studies made it probable that on account of the high coronal temperature the ions existing in the corona emit very intensively in the regions referred to (600-900 Å). On the other hand the results from an analysis of the ionization of the *E*-layer during the 11-year cycle have been interpreted in the above mentioned way [3]. As the monthly mean of the intensity of radiation responsible for the ionization of the *E*-layer can be well represented by the relative sunspot-number, still better by the regions of chromospheric faculae, it had to be taken into consideration that these regions might be the sources of the radiation producing the *E*-layer. The result, being that at the maximum of solar activity the intensity of this radiation is twice as strong as at the minimum, is a support for the suggestion, that the radiation originates in the corona, as at the maximum the temperature of the corona—and thus its radiation—is much greater than at the minimum. The intensity of the coronal line 5303 Å varies in the ratio of about 3:1. The extent of the regions of faculae has an amplitude of 15:1, which is still higher in intensity, as at the maximum of solar activity the regions of faculae are not only more extended but brighter than at the minimum. Were we nevertheless to abandon giving an explanation by the corona, we should assume furthermore that the undisturbed chromosphere emits an ionizing radiation too, which at the minimum of solar activity would be responsible for the ionosphere, whilst the increase of ionization at the maximum of activity should be sought in the regions of chromospheric faculae.

A possibility of localizing more exactly the source regions of the ionizing solar radiation is given by solar eclipses; it has been used for the first time during the eclipse of July 9, 1945, as reported in the following section. It should be expressively underlined that our researches refer exclusively to the ionization of the *E*-layer. This restriction has to be

made, because in this layer only, conditions are easy to investigate. The restriction might find its justification in the fact that the *E*-layer probably needs very much more radiation-energy for its maintenance than the *F*2-layer.

Coronal observations—For the ionospheric conditions during the eclipse the parts of the corona, which can be observed at the totality are of subordinate importance compared to the parts in front of the solar disk. The direct observation of the corona in front of the solar disk is impossible; it can only be deduced in an indirect way. As the Sun rotates 90° in seven days, the regions observed at the east limb seven days prior to the eclipse and those observed at the west limb seven days after the eclipse lie in the central meridian on the day of the eclipse. From continuous observations of the corona at the limb of the Sun seven days before till seven days after the eclipse the structure of the corona in front of the solar disk can thus be built up for the day of the eclipse, under the assumption that this structure undergoes no appreciable change within seven days. But this proves to be right [4], at least at times of small solar activity, as in the case of the eclipse considered, which took place only one year after the minimum of activity.

During the eclipse of July 9, 1945, for the first time, the structure of the corona in front of the solar disk had been built up according to the described method, as reported earlier [5]. We only want to recapitulate the result illustrated in Figure 1. The emitting regions of the corona (observed in monochromatic light of the line 5303 Å) are distributed very irregularly: there is a main emitting region in the southwest quadrant, two others at the east limb, but appearing in extremely shortening perspective. It is remarkable that there is no emission in the whole northwest quadrant. From this distribution of the emitting regions, the variation of the total intensity of coronal radiation 5303 Å during the eclipse has been deduced for the station Sörmjöle (Umeå), 63°.68 north and 20°.06 east, in northern Sweden, to which the ionospheric observations reported in the following section refer. This variation is illustrated in the lower part of Figure 2. From Figure 5 of the quoted report [5] the variation of the radiation originating in the faculae has been calculated too and is also illustrated in Figure 2. In both cases the intensity outside the eclipse has been established to 100. Finally Figure 2 demonstrates the intensity-variation for a radiation emitted uniformly from all parts of the solar disk (dotted line).

The effect of the irregular distribution of the centers of the corona and those of the faculae is, that in the first half of the eclipse the radiation of the corona and the faculae is stronger and in the second half much smaller than in the case of uniform distribution of the emitting regions over the Sun's disk.

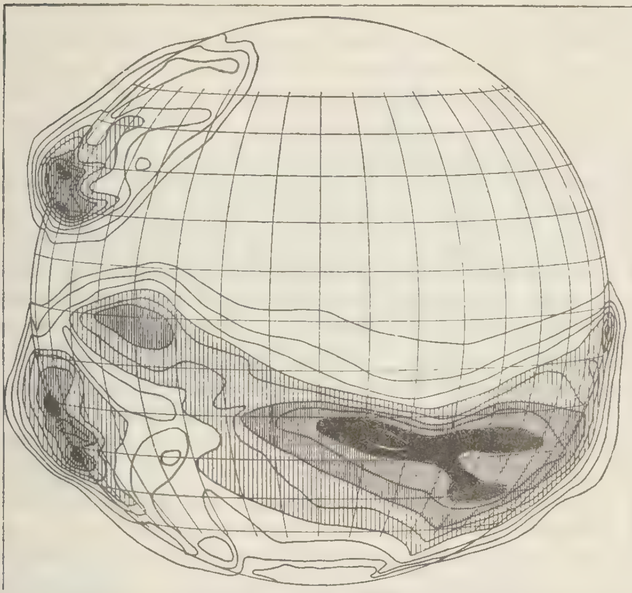

FIG. 1—DISTRIBUTION OF CORONAL RADIATIONS OVER SUN'S DISK DURING ECLIPSE OF JULY 9, 1945

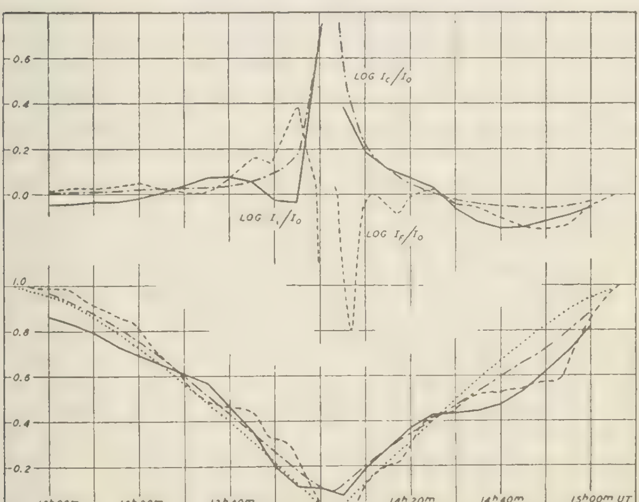

FIG. 2—VARIATIONS OF DIFFERENT SOLAR RADIATIONS DURING ECLIPSE

Ionospheric observations. O. Rydbeck recently published the ionospheric observations made during the eclipse at the already mentioned station Sormjöle [6]. From Figure 2 of that publication we took the intensity-variation of the radiation responsible for the E-layer, which has been calculated under application of a recombination-coefficient $\alpha = 1.2 \times 10^{-8}$. Rydbeck remarks: "Both the E- and $F1$-layer effects were regular and quite symmetric". This tends to prove that the ionizing radiation originates uniformly from every point of the surface of the sun. But thorough examination of the curves in Figure 2 shows that the variation of ionization differs systematically from the variation of intensity in the case of uniform distribution of the emitting sources. The greatest difference takes place between $14^h\ 30^m$ Universal Time and the end of the eclipse, where the intensity of radiation, determined through ionospheric observations, lies up to 25 per cent under the value, which has to be expected in the case of uniform distribution of the emitting sources. At the same time the curves for the radiation of the corona and the faculae show similar depressions: this is another hint that the emitting regions of the corona, respectively the faculae, are the sources of the ionizing radiation.

Identification of the sources of the ionizing radiation. A closer analysis of the curves of Figure 2 is necessary, in order to judge whether the ionizing radiation originates in the corona or in the regions of faculae. The intensity of radiation determined by ionospheric observation is called I_i, the intensity of the coronal radiation 5303 Å, I_C, that of the faculae I_F, and the intensity of a radiation emitted uniformly from the whole surface of the sun, I_0. The upper part of Figure 2 illustrates the curves $\log (I_i/I_0)$, $\log (I_C/I_0)$, and $\log (I_F/I_0)$. We now have to decide whether curve $\log (I_i/I_0)$ conforms better to $\log (I_C/I_0)$ or to $\log (I_F/I_0)$. First of all it should be kept in mind that the main emitting regions of the coronal radiation 5303 Å are closely connected to the regions of faculae, as the author [7] has found earlier and since then confirmed over and over again. This was also the case on July 9, 1945, as demonstrated by comparison of Figures 4 and 5 in the already quoted publication [5]. Therefore on the whole, I_C and I_F have a similar course, rendering it more difficult to judge whether the ionizing radiation originates in the corona or in the faculae.

From the beginning of the eclipse till $13^h\ 25^m$ I_i shows subnormal values, which can neither be explained by I_C nor by I_F, as both have supernormal values; nevertheless I_C conforms better to I_i than to I_F. From $13^h\ 25^m$ to the beginning of the totality the agreement of (I_C/I_0) with (I_i/I_0) is also much better than with (I_F/I_0). It is true that the minimum of (I_i/I_0) between $13^h\ 50^m$ and $13^h\ 55^m$ is not represented by (I_C/I_0), contrary to the strong ascent immediately before the be-

ginning of the totality, which is very well represented. During the totality and immediately before and after, the representation of I_i by I_F fails completely, whilst (I_C/I_0) agrees very closely to (I_i/I_0). During the totality, I_i and I_C both decline to nine per cent of the value outside the eclipse, the latter, as the corona is not completely covered by the Moon, whilst I_F of course declines to zero during the optical totality. Even after the totality to the end of the eclipse, on the whole the course of (I_C/I_0) conforms much more to (I_i/I_0) than (I_F/I_0), although the minimum of (I_i/I_0) between 14^h 40^m and 14^h 45^m is much better represented in (I_F/I_0) than in the course of (I_C/I_0).

As a result of the investigation, we come to the conclusion that the variation of I_i agrees much better with I_C than with I_F and that, during the totality, it can be only explained by I_C. Our earlier assumption that the ionizing radiation responsible for the E-layer originates in those parts of the innermost corona, in which the line 5303 Å appears very intensively, has thus been confirmed.

Final remarks—As for the intensity I_i, it is to be said that its course changes appreciably with an other choice of the recombination-coefficient (compare Figure 13 of the publication of O. Rydbeck). There is furthermore to note that the E-ionization often shows irregular deviations from the normal daily variation, which still have to be cleared up, and which, if they occur at times of eclipses, make the interpretation of the registrations more difficult or impossible. The subnormal I_i = values at the beginning of the eclipse might be due to such an anomaly. During future eclipses the ionospheric measurements should be made at intervals of not more than one minute.

As for I_F, there is to be observed that the ionizing radiation has been assumed proportional to the projected surface of the faculae, independently of their visual brightness.

As for I_C, it is to be said that the intensities have been estimated and expressed in arbitrary units. As all of them have been determined at the limb of the Sun, they consist of the contribution of all elements contained in a column tangential to the Sun, whilst the intensities in front of the solar disk consist only of the elements contained in the half part of that column. It would therefore be correct to reduce the intensities on the solar disk by a factor of about 2 against the limb-intensities. In fact that would bring I_C in still better agreement with I_i. It is surprising that the visual coronal radiation 5303 Å conforms so closely to the ionizing coronal radiation. This is, for instance, not the case with the coronal line 6374 Å, which shows a more uniform distribution. This behavior is easy to understand, for the line 6347 Å (Fe X) already occurs at relatively low temperatures, as found in nearly all regions of the corona, whilst the line 5303 Å (Fe XIV) appears only in regions of

higher temperature, these being at the same time the sources of the enhanced ionizing radiation.

The author is indebted to Dr. Helmut Müller for the calculations of the I_C- and I_F-variations.

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Swiss Federal Observatory,
Zurich, Switzerland, May, 1947

MICROWAVE SKY NOISE

By A. E. Covington

A sensitive microwave receiver capable of measuring small differences of radiant energy in the 3000-Mc band has been constructed after the manner of Dicke [see 1 of "References" at end of paper], and is used to measure the radio noise from the sky at Ottawa, Canada. A continuous record is obtained by means of a recording milliammeter. The receiver is calibrated by measuring the temperature of a resistance which has been substituted for the antenna; thus the equivalent temperature of the sky is used as a measure of the sky noise.

The records taken during the period April 30 to July 23, 1946, were interrupted to make improvements in the receiver, and by occasional failure of the set. During this period, an antenna with a cone of acceptance of 30° to the half-power points was used. After July 27, a continuous record was taken using an antenna with an acceptance cone of 6°. In each case the antenna was pointed toward the zenith with the electric vector in the magnetic east-west direction. The narrow-beam antenna is astronomically mounted so that solar noise observations can be taken: when this antenna points more than 15° away from the Sun, no solar noise can be received, and the background noise is measured independently.

The first strong noise fluctuations were 20°K amplitude on a background of about 75°K, and consisted of two oscillatory bursts of energy, each lasting about eight minutes. These appeared on the afternoon of May 6 at 19^{h} 25^{m} and 20^{h} 06^{m} hours GMT. Near these times, the *H*- and *D*-traces of the magnetograms from Agincourt exhibited two sharp movements in opposite senses, appearing as a distorted *U* in the traces, and resulting in a shift in the general levels. Later, a sudden-commencement storm appeared at 22^{h} 25^{m} and reached a maximum of disturbance in the night. During the violent magnetic fluctuations, the sky temperature showed only a gradual decline from early afternoon values to a constant night value. On the night of May 10, a noise storm (Fig. 1, Curve *a*) was accompanied by an auroral display, the noise increasing in intensity with the movement of the display from north to south. This marked the beginning of a magnetic and ionospheric storm, increasing in severity during the next four hours. The hourly ionospheric readings taken at Ottawa [2] show the presence of the abnormal *E*-layer and a spread *F*-layer at midnight, then complete absorption at the end of the four hours. During the violent magnetic fluctuations, the sky temperature again remained relatively constant. On the magnetically calm days preceding the storm-period of May 6-11, there was little variation in sky

temperature, and it was concluded there was no correlation with the quiet-day solar magnetic variation.

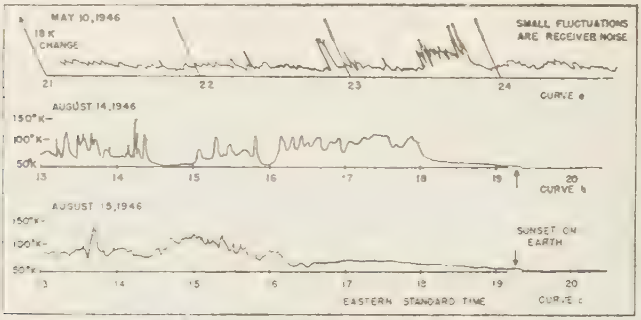

FIG. 1—NOISE STORMS DURING MAGNETIC STORMS

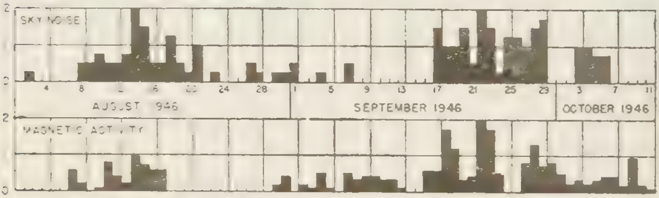

FIG. 2—SKY-NOISE CHARACTER-FIGURES (ARBITRARY) AND AMERICAN MAGNETIC CHARACTER-FIGURES

Other attempts to obtain instantaneous correlations with magnetic storms reveal a few more cases. A more general, though less accurate correlation, has been obtained by assigning arbitrary character-figures to the daily noise fluctuations. These noise figures, together with the American full-day magnetic character-figures [3] have been plotted in Figure 2. During this period the magnetic and noise storms both reached a maximum severity on the same days, August 14 and September 22. The storm of August 14 was followed on the next day by a similar disturbance of reduced intensity (Fig. 1, Curves b and c). For these two days, a corresponding similarity in the daily magnetic storms was also noted. The equinoctial magnetic storm of September was accompanied by evening auroral displays and associated abnormal E-layer ionization. The noise records show a corresponding evening activity, as well as the mid-day storms. Although abnormal E-layer was reported during the meteor shower of October 9, 1946, the noise records show no increase.

On May 6, the decline of the sky temperature from an afternoon value to a night value was most pronounced 20 minutes after sunset on Earth. This small drop of about 8°K has been noticed on a few other days (Fig. 1, Curves b and c). A corresponding increase of sky temperature some minutes before sunrise on Earth has also been noted. This effect,

apparently associated with sunrise and sunset in the upper atmosphere, is infrequent, and once occurred exactly at sunrise on Earth instead of before.

Although the present data point to a strong relationship between microwave sky noise and geomagnetic activity, further work will be needed before any explanation can be attempted.

The writer sincerely appreciates the assistance and cooperation given by members of the Dominion Observatory, Ottawa.

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Electrical Engineering and Radio Branch,
National Research Council,
Ottawa, Canada, March 28, 1947

NOTES

(See also pages 355, 367, 374, and 412)

(30) *Magnetic and general geophysical observatory in New Guinea*—Chief Geophysicist, J. M. Rayner, of the Australian Bureau of Mineral Resources, advises that the establishment of a magnetic and general geophysical observatory in New Guinea is in contemplation. This will be a most important addition for wide coverage in the world network of magnetic observatories.

(31) *Manhay Magnetic Observatory*—Dr. L. Koenigsfeld, Director of the Manhay Magnetic Observatory of the Astrophysical Institute of the Liége University, advises that geomagnetic registrations were resumed from January, 1946. Absolute measurements were begun in March, 1946, using a Kew magnetometer for declination, two QHM's (standardized at Copenhagen) for horizontal intensity, and an inclinometer (loaned by the Institut de Physique du Globe of Paris) for dip.

(32) *French Ursigrams*—Circulars from Director P. Lejay of the French Ionospheric Bureau of the Laboratoire National de Radioélectricité (196 rue de Paris, Bagneux, Seine, France) advise that French daily Ursigrams were resumed on May 19, 1947. Full details as to transmissions and codes, with coded examples, will be supplied upon request to the Bureau.

(33) *International Association of Terrestrial Magnetism and Electricity*—Effective July 1, 1947, Dr. J. W. Joyce (6641 32nd Street, Northwest, Washington 15, D. C., U.S.A.) succeeded Dr. A. H. R. Goldie as

Secretary and Director of the Central Bureau of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics. Lieutenant Commander E. B. Roberts (United States Coast and Geodetic Survey, Washington 25, D. C., U.S.A.) was also named Assistant Secretary and Director. Dr. Goldie has been Secretary and Director of the Association for many years and at the Extraordinary Assembly in Cambridge in July, 1946, asked that his resignation be made effective on or before July 1, 1947. Messrs. Joyce and Roberts are now preparing first circulars pertaining to the coming Assembly of the Association set for August, 1948, at Oslo, Norway.

(34) *International Council of Scientific Unions.*—A meeting of the Executive Committee of the International Council of Scientific Unions (ICSU) was held in Paris in July 1 and 2, 1947, with 23 members of the Committee present. Among actions taken of interest to readers of the Journal were:

Reappointment of Dr. A. Establier (UNESCO House, 19 Avenue Kléber, Paris 16e, France) as Liaison Officer between United Nations Educational, Scientific and Cultural Organization (UNESCO) and ICSU.

Announcement of formation of new International Unions as follows under ICSU: Theoretical and Applied Mechanics; Crystallography; and History of Sciences. It was agreed that new Unions only be accepted at meetings of the Executive Committee—not by postal vote—and only after six months notice so that members might consult their Unions.

It was agreed that the Unions of Physics and Biology should be invited to nominate members of the existing committees of the Union of Chemistry; also that the Union of Biology should form a Joint Commission on Radio-Biology and should invite the Unions of Chemistry and Physics to nominate members. Following discussion it was agreed that each joint commission should be allotted to a mother-union who would exercise some control over its activities and work; in accordance with this action the mother-unions were indicated for the various joint commissions, as follows: Ionosphere, Radio-Science; Oceanography, Geodesy and Geophysics; Physico-Chemical Constants, Chemistry; Radio-Meteorology, Radio-Science; Solar and Terrestrial Relationships, Astronomy; and Viscosity, Physics.

The next meeting of the Executive Committee is to be held in 1948 at Brussels at a time which shall not conflict with the assemblies of international unions and other international bodies which have already been set.

UNTERSUCHUNGEN ÜBER DIE 27-TÄGIGE WELLE DER KOSMISCHEN STRAHLUNG

Von H. Gheri und R. Steinmaurer

Zusammenfassung—Die Untersuchung der harten Komponente der kosmischen Strahlung (kS) während der Sonnenrotationen Nr. 1410-1448 Bartelsscher Zählung nach modernen Methoden der Periodenforschung zeigt das Vorhandensein einer persistenten Welle der kS, deren Amplitude mit der von Vallarta berechneten im wesentlichen übereinstimmt. Die Welle tritt in Zeiten sehr starker Sonnentätigkeit hinter Störungen zurück, die mit dem Passieren von grösseren Fleckengruppen durch den Zentralmeridian der Sonne und mit magnetischen Stürmen parallel gehen.

(I) *Problemstellung*

Bereits im Jahre 1936 leiteten V. F. Hess and H. Graziadei [1] aus einem drei Jahre umfassenden Beobachtungsmaterial der Hafelekarstation bei Innsbruck (2300 m ü. M.) einen 27.2-tägigen Gang der kosmischen Strahlung (kS) ab, der mit dem synodischen Sonnenumlauf zusammenzuhängen schien. Zu einem ähnlichen Ergebnis gelangte später auch Kolhörster [2], auch Wäffler [3] konnte aus Registrierungen auf dem Jungfraujoch, Gill [4], Monk und Compton [5], und Forbush [6] aus Carnegie-Beobachtungen die 27-Tage-Welle ableiten. Alle Untersuchungen beziehen sich auf die harte Komponente der kS.

Es schien aber von Interesse, diese Ergebnisse an einem umfangreichen, möglichst lückenlosen Beobachtungsmaterial mit modernen statistischen Methoden zu überprüfen und dabei auch die Art der Schwankung näher zu untersuchen. Während nämlich Hess und Graziadei sowie Wäffler ein dauernd bestehendes periodisches Phänomen, also eine persistente Welle, zu finden glaubten, setzt sich nach Ansicht von Forbush der Vorgang aus stückweise periodischen Wellen zusammen, wäre also nur quasipersistent. Monk und Compton weisen wiederum darauf hin, dass es sich auch nur um ein blosses Wiederkehrphänomen handeln könne. Die Extremwerte eines Intervalls, zwischen denen keine Phasenbeziehungen bestehen müssen, wiederholen sich nach gleichen Zeitabständen mit veränderlichen Amplituden. Sie können verschwinden und neue Extremwerte an anderer Stelle wieder entstehen. Ähnlicher Ansicht ist auch Gill.

Ob die 27-tägige Schwankung der kS eine persistente Welle oder ein Wiederkehrphänomen ist, hängt mit ihrer Entstehung zusammen. Nimmt man an, dass die Sonne ein permanentes Magnetfeld besitzt, das im wesentlichen mit dem eines Dipols übereinstimmt, dessen Achse gegen die Rotationsachse der Sonne um 6° geneigt ist, so ist, da sich im Verlaufe einer Sonnenrotation der Öffnungswinkel und die Lage des Störmer-

Sonnenkegels zum Erdkegel ändert, nach Vallarta [7] eine 27-tägige periodische Welle zu erwarten. Die beobachteten Schwankungen können aber auch ihre Ursache in aktiven Zentren der Sonne haben, die oft mehrere Rotationen lang wirksam sind und die ihre Stellung nicht wesentlich ändern. Diese Zentren können indirekt über das Magnetfeld der Sonne oder der Erde die Strahlungsintensität beeinflussen. Die hohe Korrelation zwischen Strahlung und Flocken, die Kolhörster [2] fand, spricht für solche Beziehungen. In diesem Falle aber dürften wir nur ein Wiederkehrphänomen oder höchstens einen quasipersistenten Vorgang finden. Natürlich können auch beide Ursachen, Dipolcharakter der Sonne und aktive Zentren, zusammenwirken.

(II) *Übersicht über die in Betracht kommenden Rechenverfahren* [10, 11]

(1) *Mittelwertbildung*—Das primitivste Verfahren, das Vorhandensein einer vermuteten Welle der Länge L festzustellen, besteht darin, dass das Beobachtungsmaterial in Abschnitte von der Länge L (Zeilen) unterteilt, abschnitteweise untereinandergeschrieben und dann spaltenweise gemittelt wird. Diese durch Mittelung gefundene Kurve stellt die im gesamten Beobachtungsmaterial enthaltene periodische Welle der Länge L dar. Übertrifft die Amplitude der Mittelwertskurve den dreifachen mittleren Fehler, so ist nur mehr mit einer Wahrscheinlichkeit von 2×10^{-3} anzunehmen, dass die Kurve nicht reell, sondern nur durch Schwankungen bedingt ist, die statistischen Gesetzen folgen.

Häufig aber kommt es vor, dass der gesetzmässige Ablauf eines Vorganges durch Störungen irgendwelcher Art beeinflusst ist, so dass die periodische Welle wohl vorhanden, aber bis zur Unkenntlichkeit deformiert ist. Wenn die Welle auch dann durch die Mittelwertsbildung herausgearbeitet wird, werden die überlagerten Störungen den mittleren Fehler so stark erhöhen, dass eine Entscheidung über die Realität nicht getroffen werden kann. Eine quasipersistente Welle würde im allgemeinen durch die Mittelwertsbildung "verwischt" werden, ein Wiederkehrphänomen wird nicht herausgearbeitet. Hier liegen die Grenzen der Leistungsfähigkeit der Methode.

(2) *Die Punktwolke*—Die Mittelung kann auch nach anderer Weise vorgenommen werden. Man berechnet von jeder aus n Beobachtungswerten (Tagesmitteln) gebildeten Zeile die erste harmonische Welle und stellt diese als Punkt mit den harmonischen Koeffizienten (a, b) als Koordinaten graphisch dar. Die zugehörigen Polarkoordinaten geben Amplitude und Phase (Lage des Maximums) dieser Welle wieder. Wird auf diese Weise jede n-tägige Welle als Punkt in einem Diagramm eingezeichnet, so entsteht eine "Punktwolke". Die Polarkoordinaten ihres Schwerpunktes geben Amplitude und Phase der 1. harmonischen Welle der gemittelten Beobachtungsabschnitte wieder. Zur Entscheidung, ob die

gefundene Schwerpunktswelle reell oder nur durch statistische Schwankungen vorgetäuscht ist, berechnet man die Expektanz $E = (2\mu/\sqrt{n})$. μ ist der quadratische Mittelwert der Abweichungen von den Zeilenmitteln, n ist die Zahl der zur Berechnung der harmonischen Welle verwendeten Werte. Falls die Amplitude der durch die Schwerpunktskoordinaten versinnbildlichten Welle das Dreifache der Expektanz übersteigt, beträgt die Wahrscheinlichkeit, dass die Welle zufällig ist nur 1×10^{-4}. Diese Methode zeichnet sich vor allem durch grosse Anschaulichkeit und Übersichtlichkeit aus, sie ist ausbaufähig und lässt auch quasipersistente Wellen, nicht aber Wiederkehrphänomene erkennen.

(3) *Das Epizyklogramm*—Obwohl die Punktwolke nur insofern von der gewöhnlichen Mittelwertsmethode abweicht, dass anstelle der n Einzelbeobachtungen die erste harmonische Welle tritt, gestattet sie einen weit tiefer gehenden Einblick in die periodischen Vorgänge. Nehmen wir an, der Schwerpunkt der Punktwolke werde nahe dem Nullpunkt, innerhalb des Expektanzkreises gefunden. Eine die Fehlergrenzen übersteigende Welle der angenommenen Länge sei also nicht nachweisbar. Betrachten wir nun nicht die Punktwolke als ganzes, sondern verbinden wir die Punkte, die zeitlich aufeinanderfolgenden Abschnitten entsprechen. Die Verbindungslinie kann nun entweder irgend eine Zickzacklinie sein, oder aber auch einen bestimmten Umlaufssinn haben. Der erste Fall tritt dann ein, wenn kein periodischer Vorgang nachweisbar ist; wandern aber die Punkte systematisch im oder gegen den Uhrzeigersinn, so ist nicht eine Periode mit der Versuchswellenlänge (auf die wir das Material untersuchten) sondern eine mit benachbarter Wellenlänge vorhanden. Wandern die Punkte im Uhrzeigersinn, so wurde die Versuchswellenlänge zu lang gewählt, findet eine Verschiebung gegen den Uhrzeigersinn statt, so war die Versuchswellenlänge zu kurz. Der Polygonzug, der die Einzelpunkte der Wolke verbindet, wird *Epizyklogramm* genannt.

(4) *Das Phasendiagramm* Gebräuchlicher und anschaulicher noch ist ein Verfahren, das als Sonderfall des Epizyklogramms aufgefasst werden kann, das Phasendiagramm.

Trägt man sich, z. B. aus der Punktwolke, die Phasen der 1. harmonischen Wellen in den aufeinanderfolgenden Abschnitten als Ordinaten gegen die Nummern der Abschnitte als Abszissen auf, so ist dies bereits ein Phasendiagramm. Meist aber findet man mit diesen groben Schritten, mit einer Verschiebung des Analysenintervalls um L Einheiten, nicht das Auslangen, sondern man wendet eine feinere "progressive Analyse" an, indem man das Analysenintervall jeweils nur um wenige Einheiten (z. B. Tage) verschiebt.

Mit dem geringsten Rechenaufwand wäre eine Analyse folgendermassen durchzuführen: Wir zerlegen unser Beobachtungsmaterial mit den

Elementen $y_1, \cdots y_n$ in Abschnitte von der Länge der Versuchswelle l ($l = L$) und analysieren die Folge $y_1 \cdots y_l$ harmonisch. Dann ersetzen wir y_1 durch das Element y_{l+1} und erhalten durch eine einfache Umrechnung die harmonischen Koeffizienten der Folge $y_{l+1}, y_{l+2}, \cdots y_{2l}$, dann wird das zweite Element und weiterhin alle folgenden durch das $(l + 2)$te, $(l + 3)$te, usw. ersetzt.

Im Phasendiagramm wird also die zeitliche Änderung der Phase graphisch dargestellt. Ist die untersuchte Welle streng periodisch, so zeigt das Phasendiagramm entweder eine Parallele zur Abszissenachse (Versuchswellenlänge-Wellenlänge der gesuchten Welle), oder liefert eine gegen die Abszissenachse geneigte Gerade (Versuchswelle $\neq$ gesuchte Welle). Aus der Phasenänderung lässt sich die genaue Länge λ der gesuchten Welle finden mittels der Beziehung $\lambda = 2\pi/(2\pi/l + \Delta\psi/\Delta t)$ ($\Delta\psi$ Phasenänderung bei Verschiebung um Δt Werte). Diese Methode zeigt auch die allfällige Existenz von Nachbarwellen; sie ist besonders wertvoll, wenn eine Welle sich sprunghaft ändert oder verschwindet und daher zur Untersuchung quasipersistenter Wellen geeignet. Es ist eine Untersuchung der Feinstruktur der Welle. Darin liegt der Vorteil aber auch der Nachteil der Methode. Estreten im Diagramm nicht nur Störungen und Änderungen im Wellencharakter hervor, die von Interesse sind, sondern auch für die unvermeidliche Messfehler für langperiodische Änderungen ist die Methode weitaus empfindlicher als eine Mittelwertsmethode.

Neben dem Phasendiagramm kann in gleicher Weise auch ein Amplitudendiagramm entworfen werden, bei dem als Ordinaten statt der Phasen die Amplituden aufgetragen werden.

(5) *Die Methode von Chree zur Untersuchung von Wiederkehrerscheinungen*—Den Übergang von quasiperiodischen zu unperiodischen Vorgangen bilden die Wiederkehrerscheinungen. Treten z.B. in unserem Analysenintervall eine Reihe von Maxima auf, so kann es vorkommen, dass sich einige im nächsten Intervall und in den folgenden wiederholen, aber geänderte Amplituden aufweisen, andere Maxima ausfallen, wahrend neue an anderer Stelle entstehen. Das bekannteste Beispiel für ein solches Wiederkehrphänomen ist die Fleckentätigkeit der Sonne. Die strenge Phasenkonstanz zwischen zwei aufeinanderfolgenden Maxima, die für eine Welle charakteristisch ist, wird bei einem Wiederkehrphänomen nicht gefordert. Der Vorgang ist nicht mehr durch eine einzige Welle bestimmter Länge zu beschreiben, sondern könnte nur durch eine Reihe von Wellen gleicher Wellenlange aber verschiedener wechselnder Amplitude und Phase dargestellt werden.

Nach Chree wird auf Wiederkehrwellen folgendermassen untersucht: Das Beobachtungsmaterial wird in Abschnitte gleicher Länge zerlegt und die fünf höchsten Werte aus jedem Intervall herausgegriffen. Von diesen "Nullwerten" ausgehend werden die nachfolgenden von $+1$ bis $+n$,

die vorhergehenden von -1 bis $-n$ durchnummeriert. Die Werte mit gleichem n werden untereinander geschrieben und gemittelt. Eine zweite Tabelle für die fünf niedrigsten Werte wird in gleicher Weise aufgestellt. Die graphische Darstellung dieser Mittelwerte ergibt die positive und negative Chree-Kurve. Noch besser als in der positiven oder negativen Kurve ist ein Effekt in der Differenz beider (Differenzkurve) erkennbar.

(III) *Ergebnisse der Analyse*

(1) *Das Beobachtungsmaterial*—Für die vorliegenden Untersuchungen wurde das Beobachtungsmaterial der Hafelekarstation aus den Jahren 1936 bis 1939 verwendet. Es umfasst 30 vollständige Sonnenrotationen, denen nach der Bartelsschen Zahlung die Nummern 1410-1436 und 1438, 1443, und 1448 zukommen. Die Nummern 1410-1419 liegen im Jahr 1936, 1420 bis 1432 i.J. 1937, 1434 bis 1436, 1438, 1443 i.J. 1938, und 1448 i.J. 1939. Die Rotationen 1424 (19.4.-15.5. 1937), 1434 (14.1.-9.2. 1938), und 1435 (10.2. 8.3.1938) enthalten Tage mit starken magnetisschen Stürmen, an denen extreme Minima auftraten. Sie wurden daher ausgeschieden. Das Messgerät war eine Ionisationskammer Steinkescher Bauart, die durch einen Panzer von 10 cm Blei und 7 cm Eisen allseitig abgeschirmt war. Ausgangsmaterial waren die Tagesmittel der Strahlungsintensität, die zwischen den Grenzen 2350 und 2500 *mI* liegen. Einem Tagesmittel kommt unter Berücksichtigung aller Messfehler und des statistischen Charakters des Strahlungseinfalles ein mittlerer Fehler von ± 3.27 *mI* zu.

Von der Überlegung ausgehend, dass der Luftdruckkoeffizient keine konstante Grösse ist, war bei früheren Bearbeitungen des Hafelekar-Materials meist monateweise korrigiert worden. Da aber die Koeffizienten zwischen 6 und 11 *mI*/Torr schwankten, entstanden an den Monatsübergängen oft Unstetigkeitsstellen, die bei Anwendung von Mittelwertmethoden keine wesentliche Rolle spielen, aber z.B. beim Phasendiagramm beträchtlich stören würden. Vor Berechnung dieses Diagrammes wurde daher mit einem einheitlichen Luftdruckkoeffizienten von 8.24 *mI*/Torr (Jahresmittel für 1936 und 1937) auf einen Druck von 580 Torr korrigiert. Es musste auch der jahreszeitliche Gang der Strahlung eliminiert werden. Von einer Korrektur auf konstante Aussentemperatur wurde abgesehen, da der Temperatureffekt nur 1/10 des Luftdruckeffekts ausmacht.

(2) *Die Analyse auf eine 27-tägige Welle*—(*a*) Bei der Anwendung der gewöhnlichen *Mittelwertmethode* wurden die Tagesmittel des gesamten Beobachtungsmaterials entsprechend den Rotationsperioden nach Bartels in Intervalle von je 27 Tagen zusammengefasst und gemittelt. Fig. 1*a* zeigt das Ergebnis, eine klar ausgeprägte Welle mit einer Schwankung von 10 *mI*, deren Maximum, wie die 1. harmonische Welle erkennen

lässt, etwa auf den 3. Tag Bartelsscher Zahlung fällt. Um die Welle auf ihre Persistenz zu prüfen, wurde das Material in Gruppen zu 10 Rotationen zusammengefasst. Das Eregebnis zeigen die Figur 1*b* bis 1*d*, bei

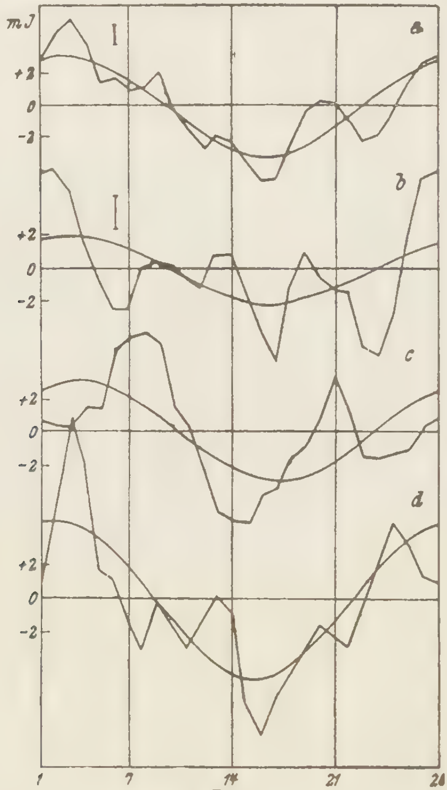

FIG. 1—MITTELWERKURVE

denen die 27-Tage-Welle mit fast unveränderter Phasenlage gut zum Ausdruck kommt.

Zur näheren Diskussion wurde die gefundene Welle mit der "Vallarta"-Welle verglichen: Nach der Theorie müsste die Welle für das Hafelekar eine Schwankung von 20 *mI*, also doppelt soviel als gefunden, aufweisen. Es ist aber durchaus möglich, dass das Maximum der Vallarta-Welle in einigen Fällen durch Störungen (ev. magnetischer Art oder Sonnenfleckeneinflüsse) verwischt wird. Dafür spricht auch eine nähere Untersuchung der mittleren Fehler. Wenn die Streuung der Tagesmittelwerte nur durch die statistische Natur des Strahlungseinfalles und durch die

Apparatefehler bedingt wäre so wäre der mittlere Fehler eines Punktes in Fig. 1*a* 0.45 *mI*. Für einen beliebig herausgegriffenen Tag berechnet ergibt er sich aber zu 1.4 *mI*, ist also dreimal so gross. Dies zeigt, dass ausser rein zufälligen Schwankungen noch Störungen vorhanden sind, deren Ursache im weiteren noch zu untersuchen sein wird. Das Ergebnis der Mittelwertmethode spricht für die Existenz einer 27-tägigen persistenten Welle, ähnlich der von Vallarta aus der Theorie geforderten, der aber noch Störungen überlagert sind.

(*b*) Noch deutlicher als aus der Mittelwertmethode geht aus der *Punktwolke* (Fig. 2) die starke Störung der periodischen 27-tägigen Welle

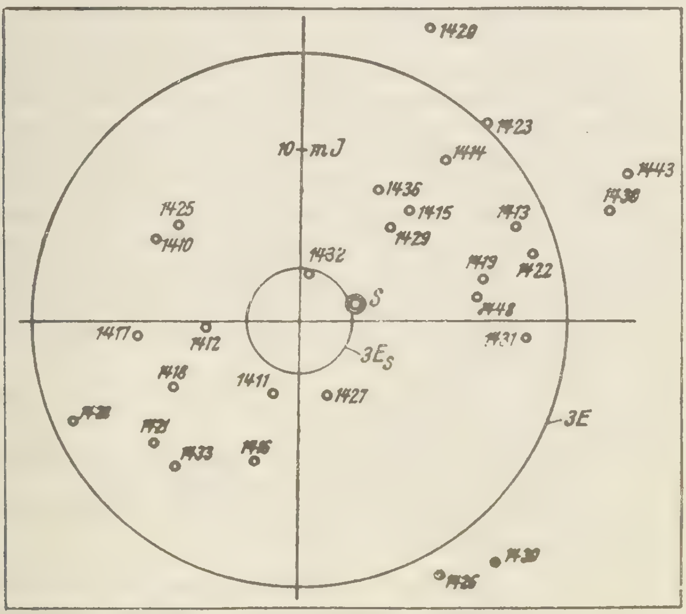

FIG. 2—PUNKTWOLKE

hervor. Der Schwerpunkt hat eine Phase von 20° und eine Amplitude von 3.4 *mI*. Er stimmt—wie es aus rechnerischen Gründen auch sein muss mit der 1. Harmonischen in Fig. 1*a* recht gut überein. Die Verteilung der Einzelpunkte in der Wolke ist ziemlich regellos, doch liegen bemerkenswerterweise die meisten Punkte im 1. und 3. Quadranten. Da keine systematische Wanderung in den Punkten zu erkennen ist (Punktwolke als Epizyklogramm aufgefasst), kann auch nicht auf das Vorhandensein einer Welle anderer Länge geschlossen werden.

Die Expektanz $E = (2\mu/\sqrt{n})$ gilt nur für eine Gauss'sche Verteilung;

daher musste untersucht werden, ob das Material diese Voraussetzung erfüllt. Hierzu wurden die 729 Tagesmittel der Rotationen ihrer Grösse nach in Klassen mit der Breite von je 2.5 *mI* eingeteilt und die Anzahl der Tagesmittel in jeder Klasse ausgezählt. Die erhaltene Kurve passt sich einer Gauss'chen Verteilungskurve gut an. Die aus der Kurve gefundene Streuung der Tagesmittel beträgt 13.9 *mI*. Daraus wird die Expektanz für den Einzelpunkt der Punktwolke ($n = 27$) zu 5.35 *mI* und für den Schwerpunkt ($n = 729$) zu 1.03 *mI* berechnet. In Fig. 2 ist der Kreis der dreifachen Expektanz für einen Einzelwert und für den Schwerpunkt eingetragen. Wie man sieht, fällt der Schwerpunkt praktisch mit der dreifachen Expektanz zusammen. Auch das Verfahren der Punktwolke spricht für das Vorhandensein einer 27-tägigen, aber stark gestörten Welle.

(*c*) Figur 3 zeigt das *Phasendiagramm* für die Rotationen 1410 bis 1424 (6.4.1936 bis 15.5.1937), berechnet aus den auf Luftdruckeffekt und jahreszeitlichen Gang korrigierten Werten. Als Abszisse ist die Lage des Versuchsintervalls, als Ordinate die Phase und für einige Rotationen auch die Amplitude aufgetragen. Wie schon erwähnt, bedeutet eine Parallele zur Abszissenachse, dass die 27-Tage-Versuchswelle mit der gesuchten Welle übereinstimmt. Jede Abweichung von einer 27-tägigen Welle macht sich durch eine Neigungsänderung gegen die Abszisse, bzw. durch eine Unstetigkeit bemerkbar. Aus der Darstellung lässt sich das Vorhandensein der vermuteten Welle während folgender Abschnitte, die mindestens je 54 Tage umfassen, feststellen:

Anfang der 1412. Rotation bis Mitte d. 1416. Rot. (15.6.-20.9.1936)—Phase ca 30°, Amplitude 8-17 *mI*

Mitte der 1418. Rot. bis gegen Ende der 1420. Rot. (23.11.1936-22.1.1937)—Phase ca 30°, Amplitude im Mittel 10 *mI*

Mitte der 1421. Rot. bis Ende der 1423. Rot. (10.2.-18.4.1937) Phase 30°, Amplitude 17*mI*

Während der Rotationen 1416 bis 1418 ist gleichfalls eine 27-tägige Welle, aber mit der Phase 200°, Amplitude 10 *mI*, nachweisbar. Ausserdem sind noch Wellen mit der Phasenlage von 300°-60° während der Rot. 1426-1427 und 1428-1431 erkennbar.

Da die Welle nicht durch das ganze Material verfolgt werden kann, muss untersucht werden, ob es sich um die Vallarta-Welle oder nur um ein Wiederkehrphänomen handelt. Die Methode des Phasendiagramms ist sehr empfindlich. Die zunehmende Unruhe der Kurve ab 1937, die eine vorhandene Welle sehr wohl überdecken kann, ist, wie später besprochene Untersuchungen zeigen, der Hauptsache nach durch wechselnde Fleckentätigkeit der Sonne bedingt. Für eine persistente Welle spricht der Umstand, dass während jedes der drei ersten oben herausgegriffenen

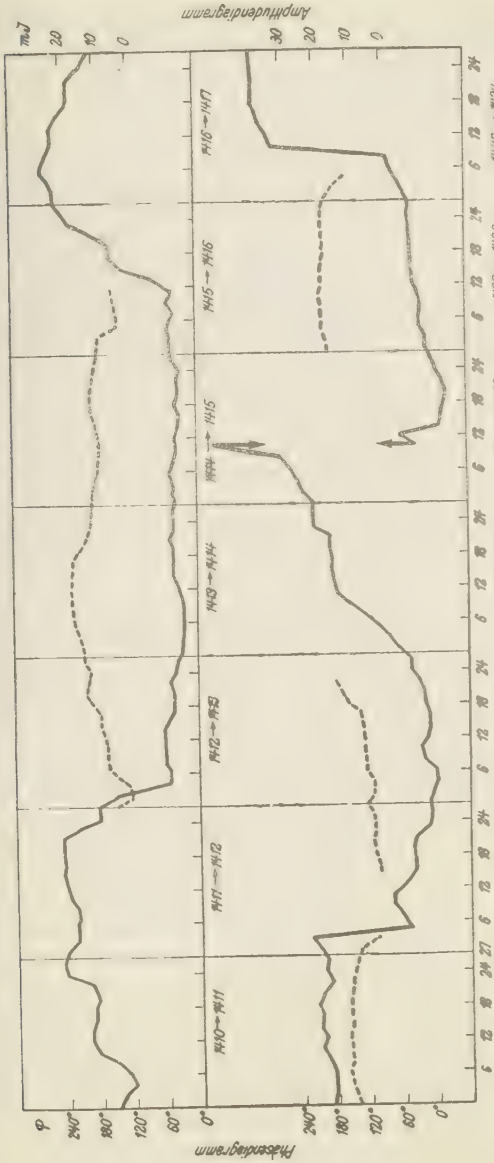

FIG. 3—PHASENDIAGRAMM (———), UND AMPLITUDENDIAGRAMM (- - -)

Abschnitte das Fleckenbild der Sonne ein anderes war. Wie Figur 3 weiterhin zeigt, beträgt die Amplitude der 1. Harmonischen während der drei betrachteten Abschnitte ca 5-17 *mI*, im Mittel also den von der Vallarta-Theorie geforderten Wert.

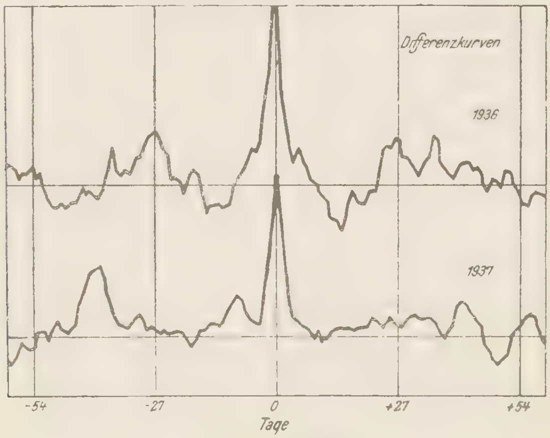

FIG. 4—CHREEKURVEN

(*d*) Figur 4 zeigt das Ergebnis der Analyse nach der *Chree-Methode*. Wie man sieht, sind Wiederkehrphänomene nicht ausgeprägt. Nur die Differenzkurve für 1936 zeigt ein Maximum nach 27 Tagen, das sich aber nach 54 Tagen nicht wiederholt. Die Kurve für 1937 lässt keinerlei 27-Tage Wiederkehr erkennen. Dieses Ergebnis ist nicht verwunderlich und widerspricht den früheren in keiner Weise. Denn die nach Vorschrift aus jedem Monat ausgewählten 5 höchsten Werte müssen durchaus nicht gerade die Maxima der Welle sein, sondern können durch irgendwelche einmalige, nicht periodisch wiederkehrende Störungen erzeugt sein.

(3) *27-tägige Welle der kosmischen Strahlung und Erdmagnetismus** — Nachdem die Analyse des Beobachtungsmaterials nach verschiedenen Verfahren übereinstimmend das häufige Vorhandensein einer ausgeprägten 27-tägigen Welle ergeben hatte, war nun zu untersuchen, ob die 27-tägigen Schwankungen der kS, in denen wir die Vallarta-Welle vermuten, vielleicht nur durch analoge Schwankungen des magnetischen Erdfeldes oder durch Sonnenfleckeneinfluss verursacht werden und welches die Ursachen des zeitweiligen Verschwindens der Welle sind.

Wie bekannt [8], ist der Einfluss des Erdfeldes auf die kS kein einheitlicher. Es wurde daher in den Phasendiagrammen untersucht, ob zwischen den Wellen der Horizontalintensität (*H*) bzw. der Charakter-

*Herrn Prof. v. Ficker danken wir für die Überlassung der magnetischen Daten der Station Wien-Auhof.

zahlen (C) und der kS konstante Phasenbeziehungen herrschen. Bei 21 untersuchten Abschnitten konnte in 13 (H) bzw. 16 Fällen (C) keinerlei Zusammenhang zwischen kS und H bzw. C gefunden werden. Nur während der Rot. 1412-1413 und 1416-1418 ist ein annähernd paralleler Gang in den Phasendiagrammen zu finden. Aber während 1413 bis 1415, wo die kS eine klar ausgeprägte 27-Tage-Welle grosser Amplitude zeigt, verläuft die H-Kurve ganz unregelmässig. Auch die Differenzen der Phasen zwischen den Wellen der kS und H zeigen keinerlei Konstanz. Zu dem gleichen Ergebnis, dass nicht der Erdmagnetismus die 27-tägige Welle der kS verursachen kann, führt auch ein direkter Vergleich der Tagesmittelwertkurven. Im Gegenteil ist sogar ersichtlich, dass in einzelnen Fällen durch magnetische Stürme das Maximum der Welle unterdrückt wurde.

(4) *27-tägige Welle der kosmischen Strahlung und Sonnenflecken** — Wenn wir die Sonnenflecken-Relativzahlen (R) zum Vergleich mit der kS heranziehen, so sehen wir in ihnen vor allem ein Mass für den allgemeinen Störungszustand der Sonne. Es ist bekannt, dass die Relativzahlen (R) eine sehr ausgeprägte 27-tägige Wiederkehrtendenz und eine verhältnismässig hohe Korrelation mit der kS aufweisen [2, 9]. Es war daher zu untersuchen, ob eine konstante Phasenbeziehung zwischen der Welle der kS und der der R bestehe. Vergleicht man dazu wieder die Phasendiagramme der kS und der R für die Rotationen, in denen die 27-tägige Welle gut ausgeprägt ist, so findet man nur recht wenig Ähnlichkeit. Das Phasendiagramm der R zeigt während der Rotationen 1416-1420 ausgezeichnete Konstanz, während bei der kS in 1416 und 1418 die Welle verschwindet. Diese Störungen sind also offenbar nicht durch Fleckeneinfluss verursacht. Auch ein direkter Vergleich der Tageswerte lässt nur wenige parallele Züge im Gang der Wellen erkennen. Bemerkenswert ist jedoch, dass sowohl bei der kS wie auch bei den Sonnenflecken mit zunehmender Rotationsnummer eine Verschiebung des Maximums von etwa 30° auf 90° und wieder zurück gegen 30° erfolgt (ersichtlich aus den Mittelwertkurven).

(5) *Störungen der 27-tägigen Welle*—Zur Untersuchung, welcher Art die Störungen sein könnten, die die Vallarta-Welle zeitweise zum Verschwinden bringen und die besonders im Jahre 1937 an sehr an Häufigkeit zunehmen, wurden H, C, und das jeweilige Fleckenbild der Sonne zum Vergleich im einzelnen herangezogen. Diese Untersuchung beschränkt sich auf das verfügbare Zahlenmaterial, erschöpfend kann sie natürlich nicht sein. Die wichtigsten Ergebnisse sind: Der plötzliche Abfall der H bei grösseren magnetischen Störungen bewirkt ein Absinken der kS. Wie schon kurz erwähnt, wurde dadurch das Maximum der Welle in Rotation 1421 unterdrückt.

*Herrn Prof. Oberguggenberger danken wir für die Bereitstellung von Tabellen und Literatur über Sonnenflecken.

Beim Durchgang starker und mittelstarker Sonnenfleckengruppen konnte fast regelmässig eine Intensitätsabnahme der kS mit einem Minimum nach 1-4 Tagen festgestellt werden, wobei im allgemeinen stärkeren Gruppen eine grössere Intensitätsabnahme entsprach. Figur 5 gibt den

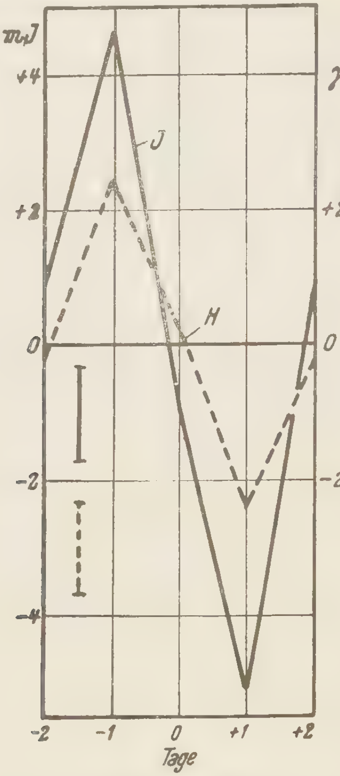

FIG. 5—STRAHLUNGSERNIEDRIGUNG BEI DURCHGANG VON FLECKENGRUPPEN DURCH DEN ZENTRALMERIDIAN DER SONNE

Mittelwert für 13 Durchgänge starker Fleckengruppen im Jahre 1936. Die Strahlung nimmt im Mittel um 9.7 mI ab. Das Minimum am ersten Tag nach dem Durchgang ist dreimal so gross als der mittlere Fehler. Die H zeigt einen ähnlichen Effekt, aber mit grösserem mittleren Fehler. Der von Hess, Demmelmair, und Steinmaurer aus magnetischen Stürmen berechnete magnetische Effekt von + 0.57 pro mille/γ reicht nicht zur vollständigen Erklärung dieses Strahlungsminimums aus.

Es wurde nun versucht, eine Strahlungskurve aus einer angenommenen persistenten 27-Tage-Welle unter Berücksichtigung der Störungen durch Fleckendurchgang und magnetische Stürme zu konstruieren und

mit der beobachteten Kurve zu vergleichen. Die Amplitude der Vallarta-Welle wurde zu 10 *ml*, die Phase zu 30° angenommen. Von ihr wurden beim Durchgang von Fleckengruppen je nach der Grösse 5-15 *ml* abgezogen. Untersucht wurden nur die ersten 16 Rotationen, denn bei den späteren war die Sonne mit Flecken so überdeckt, dass fast täglich Gruppen oder Einzelflecke den Zentralmeridian passierten. Die beobachtete Schwankung der kS stimmt qualitativ gut mit dem konstruierten Verlauf überein, nur an einigen Stellen konnte die Abweichung nicht erklärt werden. Zu manchen Zeiten extrem hohen oder niedrigen Barometerstandes besserte eine Reduktion der Strahlungswerte mit einen anderen Luftdruckeffekt die Übereinstimmung. Bekanntlich ist der Luftdruckeffekt (LE) keine Konstante. Eine Korrektur mit einem "individuellen" LE wird daher in Einzelfällen den Verhältnissen gerechter werden als die Anwendung des von uns gewählten Jahresmittels.

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Innsbruck, Austria, January 15, 1947

NOTES

(See also pages 341, 367, 374, and 412)

(35) *Joint meeting of American Section of International Scientific Radio Union and Institute of Radio Engineers*—The Secretary, Dr. Newbern Smith, of the Americas Section of the International Scientific Radio Union has notified the JOURNAL, that in view of the success attending the meetings of May 5-7, 1947, it has been decided to call a second joint meeting in Washington, D. C., October 20-22, 1947. The program of papers will, as usual, be devoted to the more fundamental and scientific aspects of radio. It is requested that authors submit titles of papers with 100-word abstracts by September 15, 1947, to Dr. Smith (National Bureau of Standards, Washington 25, D. C.)

(56) *Magnetic anomaly near Iwo Jima*—In *Hydrographic Bulletin* (No. 3014, June 14, 1947), Officers Freibergs and Genne of the Swedish motorship *Halland*, Captain H. Lundgren, report having experienced abnormal magnetic variation varying from 8° west to 2° east while in latitude 24° 50' north and longitude 141° 20' east, which is about 15 miles southward of Iwo Jima.

(57) *Aurora Borealis, May 24, 1947*—In *Hydrographic Bulletin* (No. 3015, June 21, 1947) Second Officer V. C. Brown of the American steamship *Kittanning*, Captain W. Miller, Master, reports as follows: On May 24, 1947, at 08h 15m UT, while in latitude 32° 50' north and longitude 77° 10' west, the Aurora Borealis appeared at an altitude of 30° in the northern sky and covered an arc of approximately 40° of the horizon. The display was most notable because of its bright, vertical white shafts which began near Polaris and extended through Ursa Minor. An orange-colored sector commenced at Ursa Major and "veered" to Polaris, and a "white patch," similar to the "Milky Way," extended from Polaris through Altair and Deneb to the opposite horizon. The total duration of the phenomenon was about 30 minutes.

(58) *Cheltenham magnetograms, January-June 1946*—The report "Cheltenham magnetograms, January-June 1946" was issued by the United States Coast and Geodetic Survey in June, 1947. This publication contains quarter-size reproductions of the magnetograms for the first six months of 1946 together with approximate monthly and annual mean values based on the 24th hour of each day.

(59) *Distribution of provisional sunspot-numbers*—Beginning with June, 1947, the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards will distribute the Zurich provisional sunspot-numbers. Beginning with the data for June, 1947, the sunspot-numbers will appear currently in the CRPL-F series "Ionospheric data". The first issue including these data is CRPL-F35, issued in July, 1947. Copies will be supplied regularly upon written request to CRPL, Washington 25, D. C.

(60) *Bulletin of San Miguel Observatory*—We have received the first quarterly issue of the *Boletín Mensual del Observatorio de Física Cósmica de San Miguel*, Argentina (latitude 34° 33' south, longitude 58° 44' west). It covers the months of January, February, and March, 1946. The *Bulletin* appears in a form and style similar to those of the *Boletín Mensual del Observatorio del Ebro*. The present issue is comprised of the first three issues of Volume 1. In each number there are three sections: (I) Datos diversos, (II) Registros eléctricos, and (III) Registros meteorológicos. Under Section II are included tables of values of the potential-gradient and conductivity of the atmosphere. It is planned to include next year the data for earth-currents, the apparatus for which is now in operation. There are no geomagnetic data as yet in the *Bulletin*.

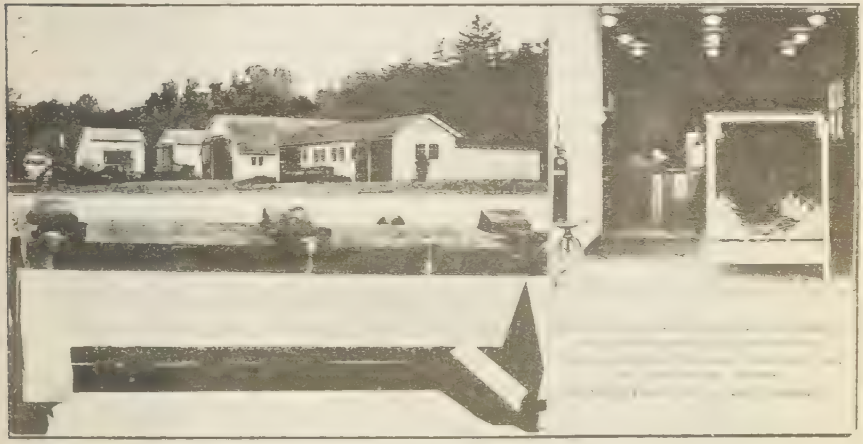
FACILITIES PROVIDED BY THE KENSINGTON MAGNETIC LABORATORY

By B. P. Ramsay and F. L. Yost

(I) *Introduction*

During World War II a number of educational and scientific institutions* entered into contracts to cooperate with the Naval Ordnance Laboratory (NOL), and contributed in large measure to the success of NOL activities. Contract NOrd-392 between the Bureau of Ordnance, Navy Department, and the Carnegie Institution of Washington (CIW) stipulated, among other things, that the Department of Terrestrial Magnetism (DTM CIW) provide and operate certain facilities for NOL.

Under the directorship of Dr. John A. Fleming, DTM CIW operated these facilities, which were known as the Kensington Magnetic Laboratory (KML), from March, 1943, to July, 1946. These facilities were housed in frame buildings, such as those shown by Figure 1. The buildings were



erected at Kensington, Maryland, under terms of the contract. Six additional buildings of the same general type were provided by NOL at various locations in Maryland, North Carolina, New York, and the District of Columbia. The specifications for these buildings required that the ma-

*Among these were such institutions as Cornell University, Bryn Mawr College, Iowa State College, the National Bureau of Standards, Woods Hole Oceanographic Institute, the American Institute of Natural Science, Massachusetts Institute of Technology, George Washington University, Stevens Institute of Technology, and the Carnegie Institution of Washington.

terials used be nonmagnetic and nonmetallic so far as possible. Copper nails and brass screws were employed, copper gutters were specified, and no steel was employed for reinforcing of concrete floors and foundations. The company to which the erection of the Kensington buildings was entrusted submitted a bid "for the construction of a nonmagnetic laboratory".

The facilities of KML included coil-systems of unusual size, design, and construction. Generically, these have been called "magnetic generators". Specific types of generators used were essentially solenoids, Helmholtz coils, and gradhelms*. The original program of work called for the simulating of magnetic fields of ships in order to determine the performance of magnetic mines developed by NOL. However, related magnetic problems were also studied and thus the scope of the program was broadened considerably to include other types of experimental work. These additional functions included measurements of basic sensitivity, of effects of magnetic latitude, of the condition of magnetization of mine-cases, of effects of magnetic circuits and of eddy-currents on mine-design, studies of flux saturation, and design of search coils. The coil-systems were used to simulate such influences as pulses which may occur during magnetic storms, oscillating fields such as may result from motions impressed on ordnance devices by tides and waves, rotating magnetic fields such as might be experienced by a body precessing in space, and gradients of various types. Except for the application of large cyclic fields for idealizing bodies in given magnetic states, the problems of KML were concerned with fields and gradients which could be expressed conveniently in milligauss and gammas, or milligauss per foot and gammas per foot.

Magnetic testing on a moderate scale had been done at NOL prior to establishment of KML. Eventually all electric and magnetic testing of mines, depth-charges, torpedoes, and their component parts was assigned to KML. In addition, experimental studies of minesweeping and magnetic effects of countermining were conducted there, and field-tests on many devices were carried out under the supervision of this laboratory.

As was the case in the establishment of all special laboratories during World War II, the problem of personnel was a difficult one. DTM CIW entered into an agreement with NOL whereby the latter would supply some of the manpower required. Under this agreement several members of the staff of NOL were released to be hired by DTM CIW for the work. Among these was Dr. Bertrand P. Ramsay, who at the time of his release was in charge of the NOL's magnetic simulation work. He was designated Physicist-in-Charge of the new facility in August, 1943, and continued in that capacity during the life of the organization. NOL also assigned

*Coil-systems for producing uniform gradients; see G. H. Shortley and A. May, J. App. Physics, 16, 841-843 (1945).

personnel to KML for temporary duty, during the contract, to supplement the staff of DTM CIW.

Dr. George H. Shortley, who was head of the Magnetic Test Division at NOL, was appointed representative of the Officer-in-Charge of NOL, and was responsible for coordination and assignment of work to KML and for providing guidance and technical advice to its staff.

All functions—contractual supervision, technical supervision, and liaison—were carried on in such a manner that KML operated as if it were an integral part of NOL.

(II) *Solenoids*

The solenoids were usually three feet by four feet in section. They were used for investigating magnetic properties of long cylindrical bodies with cross-section diameters which varied from 1/64 inch to 24 inches. More than 20 solenoids were employed for various purposes; these varied in length from 12 feet to 40 feet. The frames of the solenoids were constructed of wood, as illustrated by the example shown in Figure 2. Plyboard sides, 3/4 inch thick, provided sufficient strength to support loads of approximately one ton which were sometimes subjected to magnetic measurements. Heavy loads were rolled into the solenoids on carriages with brass wheels and stainless steel axles. Both dolly and solenoid were fitted with tracks made of brass angles (Fig. 3).

When a given solenoid frame had been assembled, it was mounted on a long pipe as axle, and manually rotated as a bobbin to wind the wires in place. The windings were uniformly distributed (Fig. 4) by setting successive windings in the machined grooves of quarter-cylinders of oak

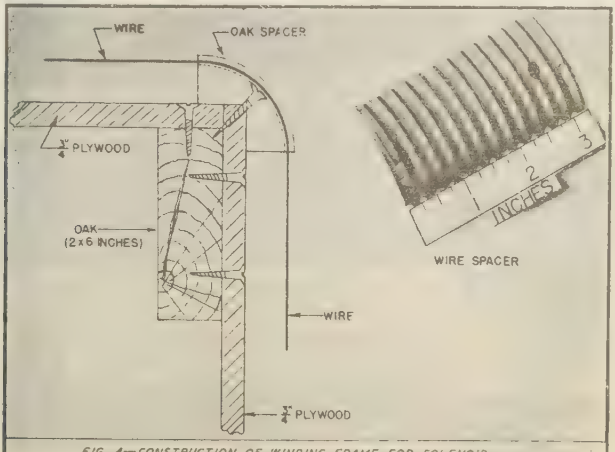


FIG. 4—CONSTRUCTION OF WINDING FRAME FOR SOLENOID

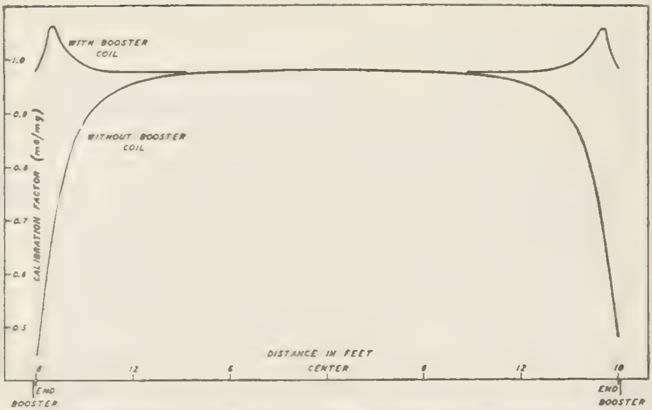


FIG. 5—MAGNETIC FIELD-STRENGTH ALONG SOLENOID AXIS AS MEASURED WITH AND WITHOUT BOOSTER COILS

or maple which were mounted at the corners of the solenoid frame. Each solenoid was provided with two independent coil-windings, which could be used independently or in series, as desirable. Copper wire, American

FIG. 6—[illegible]

FIG. 7—[illegible] FOR OUTDOOR USE

wire gage 13 or 14, was usually employed as a single turn. The hardwood cylinder which spaced the windings was machined to give four turns per inch, or two turns per inch for each coil. A spacing of two turns per inch yields a magnetic field of approximately one milligauss per milliampere. In general, solenoids were provided with auxiliary "booster-coils" which extended the region of field-uniformity toward the ends of the solenoid. Figure 5 shows values of magnetic field-strength along the solenoid axis, as measured with and without the booster-coils.

In use the solenoids were given the magnetic east-west orientation in which the component of the Earth's field is zero. A convenient method of housing long solenoids consisted in annexing "tunnels" to a laboratory work-room which provided space for instruments and operators. Solenoid tunnels of this kind are shown by Figure 6. The dimensions of the tunnels are just sufficient to contain the solenoids. For extended observations in which large variations of temperature were not objectionable, the solenoid could be used outdoors in a canvas jacket. A jacketed solenoid for outdoor use is shown by Figure 7.

(III) *Helmholtzes*

For many purposes, a Helmholtz coil-pair is more suitable than a solenoid. In the conventional Helmholtz, the two identical coils are circular in shape, and it is assumed that they should be separated by the

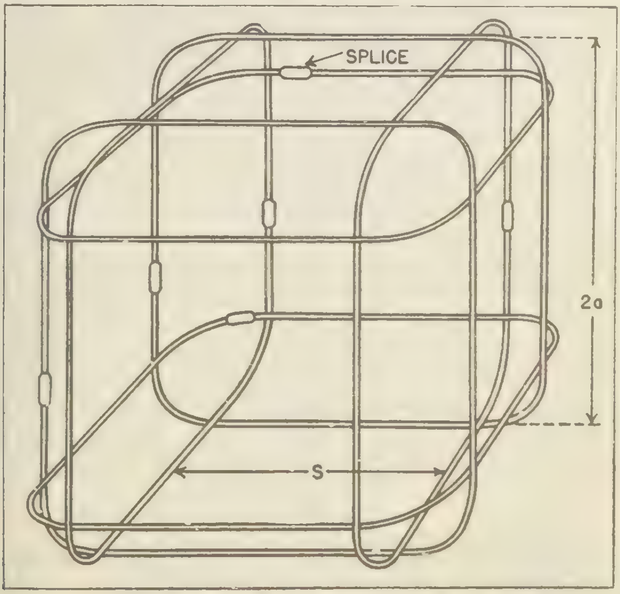


FIG. 8—ISOMETRIC DIAGRAM OF A CUBICAL HELMHOLTZ

distance s which makes the second derivative of the axial component of the field vanish at the axial point midway between the two coils. This assumption indicates that s should equal the radius of the circles. For practical reasons, the coils are made square, and three sets of coil-pairs with axes in mutually perpendicular directions are centered about a common point in order to control each component of field. A cubical Helmholtz of this sort is shown by the diagram Figure 8. For square coils, the optimum separation is $s = 1.1a$, where a is the half-edge of the square. However, for accuracies of the order desired the fields did not vary too critically with slight changes in separation from the optimum value. Increased working space and adequate accuracy for many purposes can be obtained by making the separation $s = 1.2a$. Figure 9 for this case is a working-space diagram which shows deviations in the central

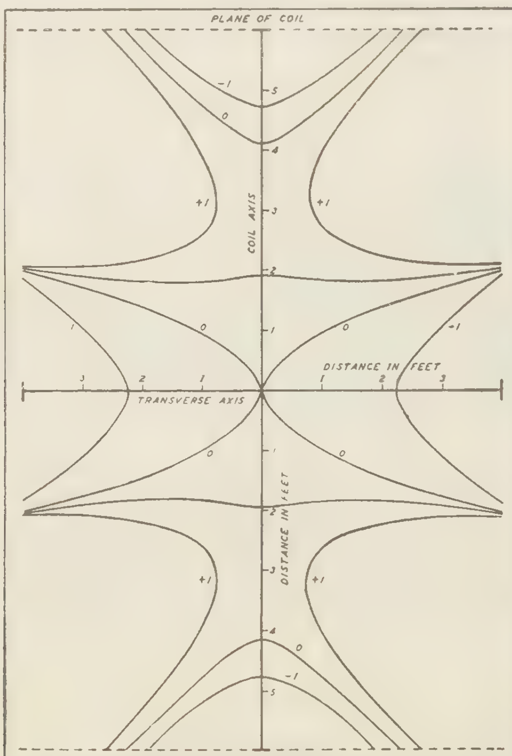


FIG. 9—WORKING-SPACE DIAGRAM FOR SQUARE-COIL HELMHOLTZ WITH 12-FOOT COIL SPACING (NUMBERS ON CURVES REPRESENT PERCENTAGE DIFFERENCE OF FIELD FROM VALUE AT CENTER; PLANE OF THE PAPER IS PARALLEL TO COIL EDGES)

plane which includes the Helmholtz axis in per cent of field-strength at the center of such a Helmholtz. Auxiliary booster-coils have been used in some instances to increase the uniformity of field.

Figure 10 shows a cubical Helmholtz which was provided by KML. Approximately one-fifth of the coil-system is below the floor. The lower coil of the vertical Helmholtz is placed in a trough six inches below the

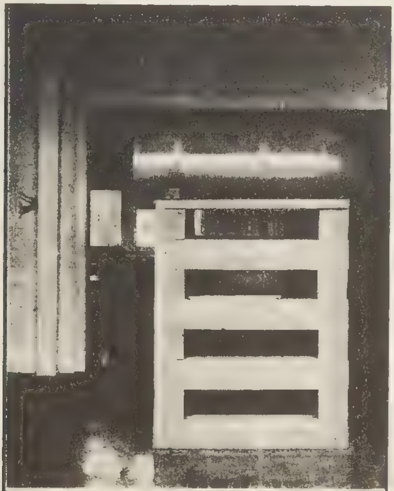


FIG. 10—CUBICAL HELMHOLTZ AT KENSINGTON MAGNETIC LABORATORY

floor; the upper coil is placed on a shelf above the door. Because the center of the Helmholtz is nearly six feet above the floor, a pigpen structure was used to support the body on which measurements were made in such a position that its axis passed through the center of the Helmholtz. The pigpen was rolled into position from a loading hoist on a hydraulic lift-truck. The coils of the Hemholtz consist of lead-sheathed cable consisting of 304 turns of single copper wire, paper-insulated. The lead-sheath was broken at the splicing juncture so as to avoid a closed metallic loop. Six leads were brought out from each turn of cable so as to form three separate coils of 100 turns each. Thus a cubical Helmholtz of this kind provides nine independent Helmholtz-pairs.

(IV) *Gradhelms*

The gradhelm is a system of four coils for producing regions of uniform field-gradient. Figure 11 is an isometric drawing which shows the ar-

rangement of the four coils. The separation of the coils of a gradhelm is shown by Figure 12, and the flux-distribution near the center of the coil-system in a plane transverse to the long dimension of the gradhelm is shown by Figure 13. In other diagrams of this Figure, field-vectors are drawn to show the manner in which the coil-system is used when the gradient-elements H_{zy} , H_{yz} , and H_{zz} are matters of interest. Figure 14 shows a gradhelm, eight feet in length, which was built at KML. Another set of coils of this type which was in use, was superposed on a solenoid and was 26 feet in length.

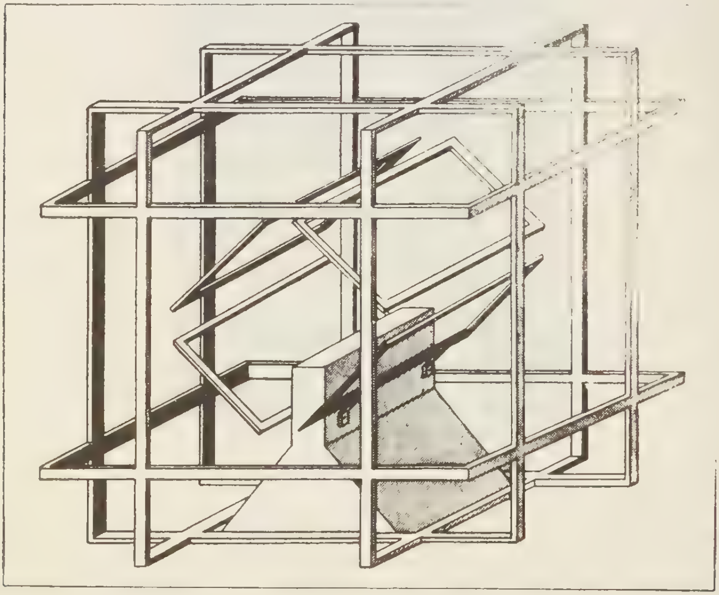


FIG. 11—ISOMETRIC DIAGRAM OF CUBICAL HELMHOLTZ WITH GRADHELM

(V) *Circuit constants*

The magnetic generators were controlled by auxiliary equipment which included suitable amplifiers with power-supply, voltage-regulators, rectifiers, and signal-generators. Collectively, a set of such apparatus is called a signal-simulator. Because the influences from several magnetic generators were superposed in various applications, it was necessary for a simulator to be capable of controlling the relative phase, as well as the contour, amplitude, and period of the several signals. The periods of general interest lay in the range from one sec to 1000 sec. The simulators were designed to operate linearly into an impedance of approximately

100 ohms. This value was chosen because it is the approximate direct-current resistance of large Helmholtz coils. Since the direct-current resistance of solenoids was less than two ohms, sufficient series-resistance

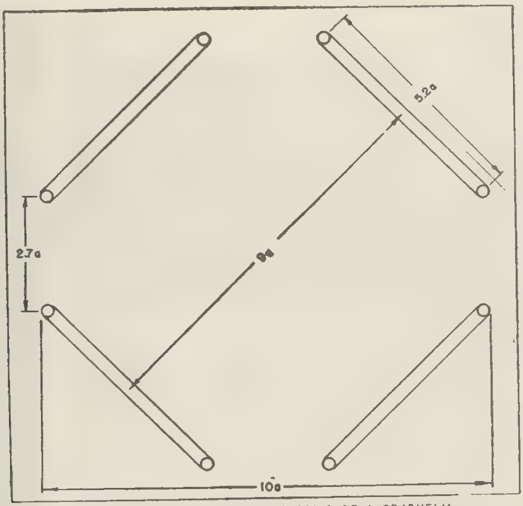


FIG. 12—SEPARATION OF THE COILS OF A GRADHELM

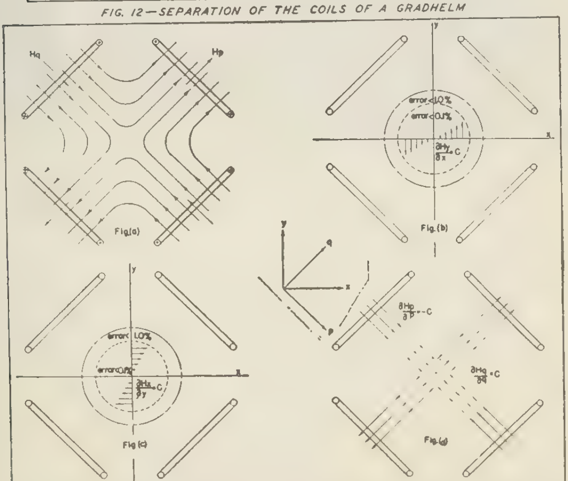


FIG. 13—FLUX DISTRIBUTION IN A PLANE TRANSVERSE TO THE LONG DIMENSION OF A GRADHELM

was used with them to guarantee linear operation of the simulators. The low resistance of the solenoids was a distinct advantage when large currents were required to produce cyclic fields for idealizing a body in a

given magnetic state. At the rather long periods employed, the effects of alternating-current resistance, inductance, and distributed capacitance were negligible.

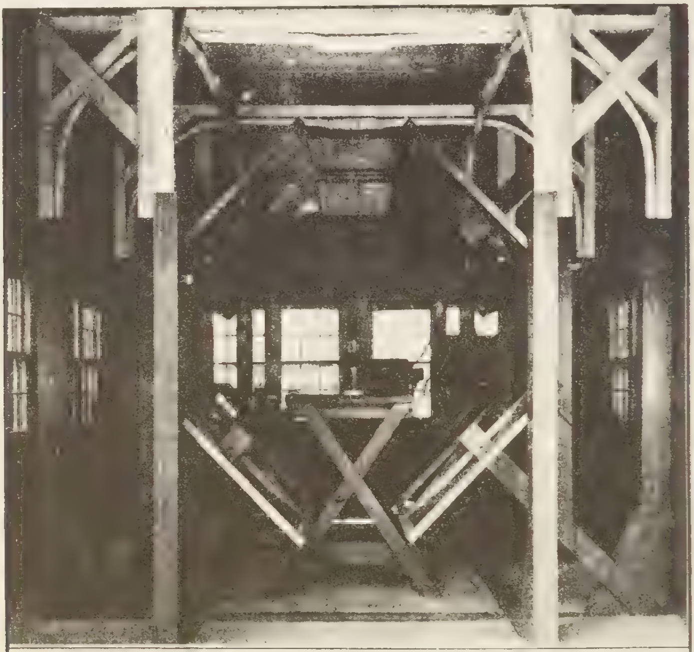


FIG. 14—GRADHELM PROVIDED BY THE KENSINGTON MAGNETIC LABORATORY

(VI) *Interaction of generators*

The number of magnetic generators which can be significantly employed in a given region depends upon the strength of magnetic influence developed by each and the accuracy which is required. At distances comparable with the dimensions of the coils, magnetic disturbances produced by a Helmholtz are much greater for a given central field-strength than those produced by a solenoid. Disturbances which result from the use of a gradhelm are relatively inconsequential in determining what separation between magnetic generators is required. An indication of how great the separation between adjacent generators should be may be based upon the assumption that tolerable errors of observation, which may result from the interaction of magnetic generators, should not be greater than one per cent. Since experimental measurements are made with field-amplitudes less than one milligauss and gradient-amplitudes less than one milligauss per foot, variations in magnetic field and field-gradients which result

from the interaction of generators should not be appreciably greater than such variations arising from natural causes. A 20-foot Helmholtz generating a sinusoidal field of amplitude 200 milligauss at the center produces a gradient-amplitude of 0.005 milligauss per foot at a distance of 105 feet, and a field-amplitude of 0.04 milligauss at a distance of 220 feet. A separation of 250 feet between a Helmholtz and a gradhelm is therefore considered adequate, but it is desirable that a Helmholtz should be removed from other field-generators by a distance of 1000 feet.

(VII) *Conclusion*

During the operation of the contract, the procedures and techniques developed at KML proved to be very valuable. Some of its methods, adopted as standard, are still being followed in magnetic and electric tests on ordnance equipment. The development of the KML coil-systems was also important because experience with them has furnished information valuable in the design of the much more precise and elaborate coil-systems which are to become important facilities of the NOL.

The contract under which these facilities were provided was terminated June 30, 1946. Some of the generators were moved to the White Oak Quiet Area of the Naval Ordnance Laboratory.

NAVAL ORDNANCE LABORATORY,
White Oak, Silver Spring 19, Maryland, May 15, 1947

NOTES

(See also pages 341, 355, 374, and 412)

(41) *College Magnetic Observatory*—The contract for the new College Magnetic Observatory of the United States Coast and Geodetic Survey has been awarded. Construction was started in July, 1947.

(42) *Manufacture of magnetometer-inductors*—we have been informed by the Precise Instrument Company, Inc., of Brooklyn, that the company is now prepared to resume construction of the CIW magnetometer-inductor of the pattern described in this JOURNAL [18, 105-110 (1913)], providing orders for a minimum of ten sets are received. Enquiries as to price, delivery date, and details should be addressed to the Precise Instrument Company, Inc., 200 Tillary Street, Brooklyn 1, New York.

(43) *Errata*—The following errata are noted for the June, 1947, issue of the JOURNAL:

Because of a blunder there are no pages 105 to 146; in order to avoid confusion pages will not be renumbered and an appropriate note will be included in list of contents in the December issue.

In the paper by W. E. May, the following changes are to be made:

Page 222, in footnote, for "no effect" read "little effect"; page 231 at end of paper for "*Buckshire*" read "*Buckinghamshire*". In second line of page 294, for "Giesicke" read "Giesecke"

(44) *Personalia*—During the summer *W. R. Piggott*, of the British National Physical Laboratory, visited the National Research Council of Canada at the invitation of its President, C. J. Mackenzie, and spent some time in Washington, D. C., before his return to England. He is personal assistant to Sir Edward Appleton, Permanent Secretary of the Department of Scientific and Industrial Research, and is concerned principally with ionospheric work.

V. A. Thomas, Scientific Aid of the United States Coast and Geodetic Survey (USCGS), reported for duty at the Sitka Magnetic Observatory on May 3, 1947.

Merril L. Cleven, Geophysicist of USCGS, completed his field-work in Alaska and returned to Washington, D. C., July 21, 1947.

James H. Baden, Geophysicist of USCGS, returned to Washington, D. C., June 28, 1947, after an extended field-trip in South America.

Cameron Cumming, Geophysicist from the Dominion Observatory, standardized his instruments at the Cheltenham Observatory prior to departing for northern Canada and Greenland on a cooperative project.

George V. Keller has been undergoing a period of training prior to departure for Tucson, where he will be an assistant at the Tucson Magnetic Observatory of USCGS during the summer months.

Professor *Carl Störmer*, head of the Institute of Theoretical Astrophysics in the University of Oslo, and Dr. *E. Delporte*, Director of the Observatoire Royal de Belgique, Uccle, have been elected Foreign Correspondents of the Paris Academy of Science.

The degree of Doctor of Science, *honoris causa*, was conferred by Oxford University May 20, 1947, on Professor *Carl Störmer*. Later on the same day he delivered the Halley Lecture on "Polar aurora in southern Norway". Professor Störmer is now Emeritus Professor of pure mathematics at the University of Oslo and, besides making distinguished contributions to that subject, has applied it to the study of the motion of charged particles in the Earth's magnetic field, thus explaining many remarkable observed characteristics of the Aurora Polaris. He has been for over one-third century, the foremost leader and organiser of auroral observation by simultaneous photography from two or more well separated stations. This work has increased knowledge of the Aurora Polaris and presented many problems for theoretical geophysicists. As by-products of his observing organisation, Professor Störmer has also made important additions to our knowledge of "mother-of-pearl" clouds and of winds in the upper atmosphere, as indicated both by such clouds and by meteor trails.

GRAPHS OF THE INDUCED MAGNETIC MOMENT AND SHIELDING EFFECT OF A SPHERICAL SHELL IN A UNIFORM MAGNETIC FIELD

By Bryant Tuckerman

This paper presents graphs of well-known formulas for the induced magnetic moment and shielding effect of a spherical shell of constant permeability introduced into a uniform magnetic field. The problem is of interest in the theory of the deviations and compensation of the magnetic compass, and in the shielding of electromagnetic instruments from external magnetic fields.

Barlow [see 1 of "References" at end of paper] in an experimental investigation of the deviations of a compass produced by spherical balls and shells, concluded, ". . . *the tangents of the deviation are proportional to the cubes of the diameters, or as the* 3/2 *power of the surface, whatever may be the weight and thickness*. . . . This law, however, I have since found to have its limits; . . . the magnetic fluid requires a certain thickness of metal, exceeding 1/30 inch, in order effectually to develop itself, and to act with its maximum of effect." The latter conclusion was based on work with ten-inch spheres.

Poisson [2] gave a mathematical solution of the problem on the basis of his theory of magnetism in terms of a parameter k, characteristic of the material. The substitution $k = (\mu - 1)/(\mu + 2)$, where μ is the permeability of the shell, assumed to be constant, in a medium of unit-permeability, transforms his equations for the induced magnetic moment and the internal field into the modern forms.

A convenient modern presentation is given by Webster [3] for an arbitrary distribution of magnetism external to the sphere. Both Poisson's and Webster's treatments use spherical harmonics.

Let the spherical shell have outer radius a, inner radius ρa, and constant permeability μ_1, while the interior and exterior regions have constant and equal permeability μ_0, and write $(\mu_1/\mu_0) = \mu$. Let the intensity of the uniform magnetic field before the introduction of the shell be H.

The field within the hollow will be parallel to the applied field and of uniform intensity $F = \lambda H = (H/S)$ where $\lambda = 1/\{1 + [2(\mu - 1)^2/9] [1 - \rho^3]\} = (1/S) =$ (Internal field / Applied field). The reciprocal $S =$ (Applied field / Internal field) is called the shielding ratio. Curves of λ and S are given in Figure 1, magnetic shielding due to spherical shell.

The field outside the sphere is the same as if the shell were removed, and at its former center there were placed a magnetic dipole, of moment $M = a^3 mH$, in the direction of the applied field, where $m = [(\mu - 1)/(\mu + 2)]/\{1 + [9\mu/(\mu + 2)(2\mu + 1)] [\rho^3/(1 - \rho^3)]\} =$ induced magnetic moment of spherical shell relative to solid sphere of infinite

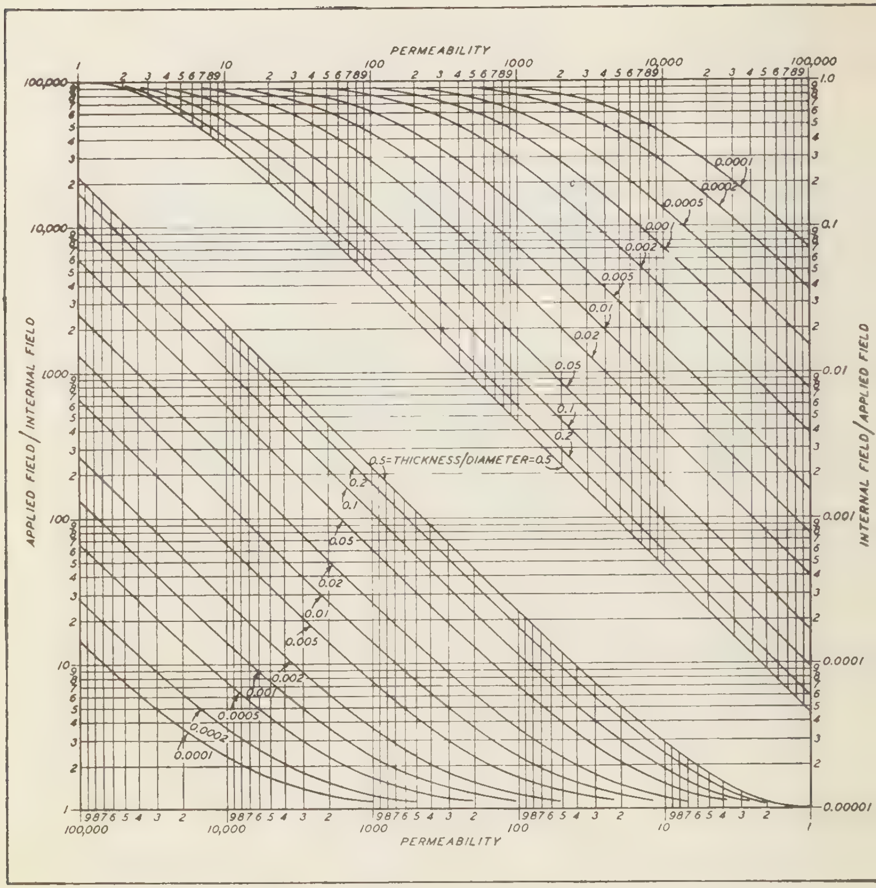


FIG. 1—MAGNETIC SHIELDING DUE TO SPHERICAL SHELL

permeability (Fig. 2). For a shell of infinite permeability, the induced magnetic moment is Ha^3.

For a solid sphere, $\rho = 0$, and $m_0 = [(\mu - 1)/(\mu + 2)]$. Hence $(m/m_0) = 1/\{1 + [9\mu/(\mu + 2)(2\mu + 1)]\,[\rho^3/(1 - \rho^3)]\}$ = induced magnetic moment of spherical shell relative to solid sphere of same permeability (Fig. 3). If $1 < \mu < \infty$ and $0 < \rho < 1$, then $0 < m_0 < 1$, $0 < (m/m_0) < 1$, and $0 < m < 1$.

The above forms of the equations for λ and (m/m_0) are based upon those given by Mascart and Joubert [4]. In the forms $(S - 1) = [(1/\lambda) - 1] = [2(\mu - 1)^2/9\mu]\,[1 - \rho^3]$, $[(m_0/m) - 1] = [9\mu/(\mu + 2)$

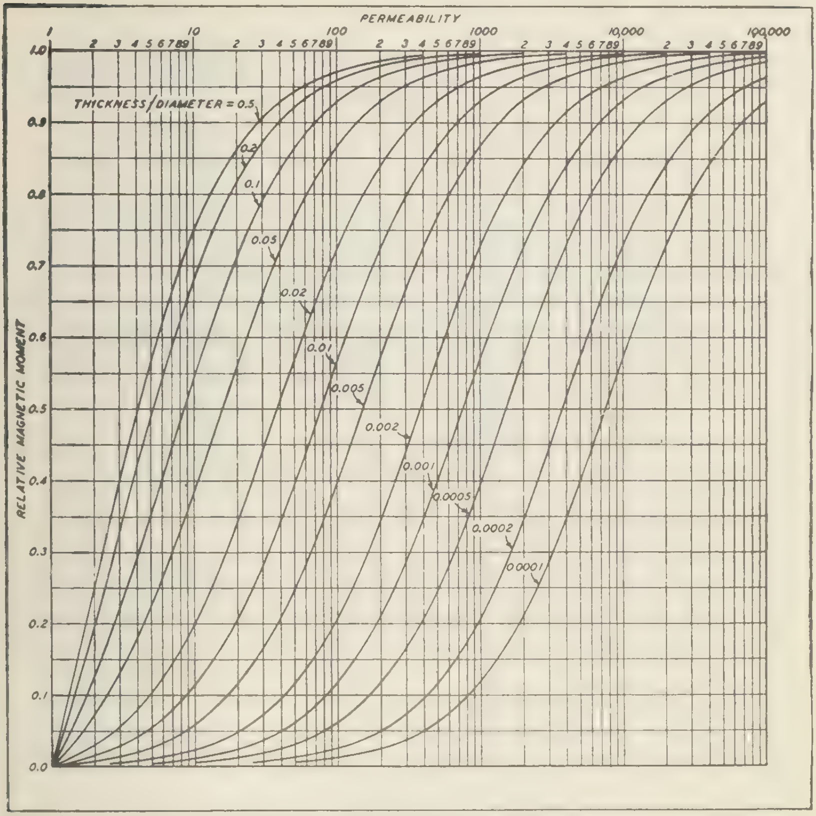


FIG. 2—INDUCED MAGNETIC MOMENT OF SPHERICAL SHELL RELATIVE TO SOLID SPHERE OF INFINITE PERMEABILITY

$(2\mu + 1)] [\rho^3/(1 - \rho^3)]$ each would be suitable for representation by an alignment-chart of three parallel linear scales.

The graphs

The scale of μ is in all cases logarithmic, with limits of $\mu = 1$ and $\mu = 10^5$. The graphs are drawn for fixed values of ρ, which for convenience in the applications are numbered in terms of the ratio (thickness/diameter) $= [(1 - \rho)/2]$. For a solid sphere, (thickness/diameter) $= 0.5$, and this graph for m represents $m_0 = [(\mu - 1)/(\mu + 2)]$. The scales of m and (m/m_0) are linear. A logarithmic scale is used for λ and $S = (1/\lambda)$; the curves are identical but one set is rotated through 180° to provide independent scales. The scale of λ, to the right, is associated with the

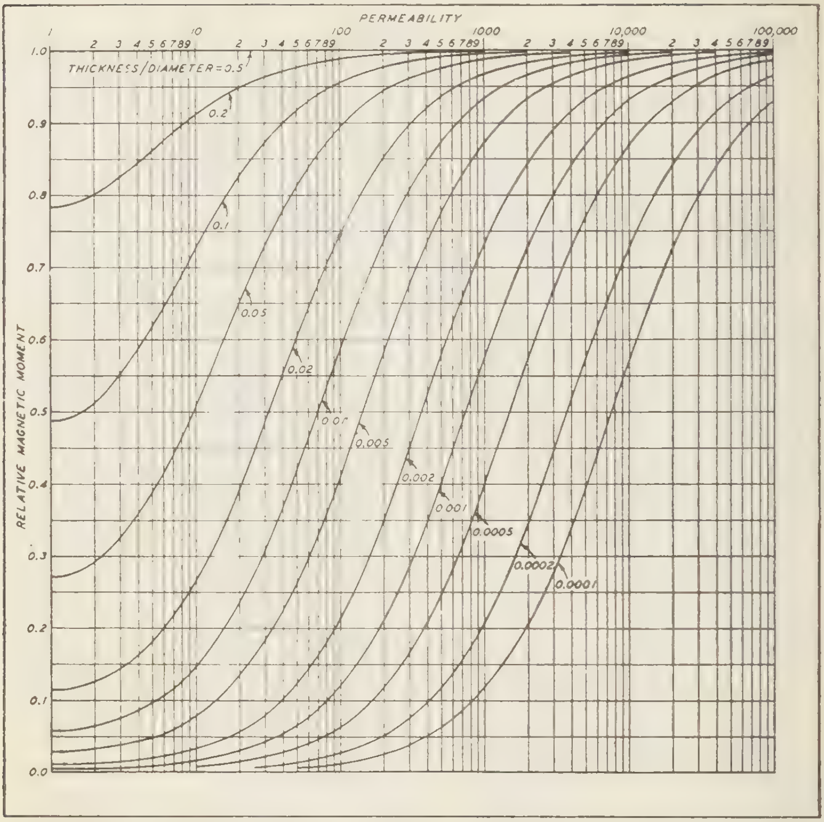


FIG. 3—INDUCED MAGNETIC MOMENT OF SPHERICAL SHELL RELATIVE TO SOLID SPHERE OF SAME PERMEABILITY

upper scale of μ; the scale of S, to the left, is associated with the lower scale of μ.

Applications

The shielding ratio S may be used in estimating the protection from external fields afforded electromagnetic instruments by a spherical shell. (It is more usual to use a cylindrical shell, and in either case the shielding ratio can be increased by the use of several nested shells with space between. A discussion is given by Dye [5]).

In the theory of the deviations of the magnetic compass [6], λ represents the "... 'mean force to north' in terms of the Earth's horizontal force as unit." For a hollow sphere, this is the λ defined here as (F/H), which can be used as an estimate of λ for a ship or tank.

The curves for m and (m/m_0) were constructed for application to the

correction of quadrantal error of the magnetic compass. In the usual compass-theory the contributions to the coefficients due to a single sphere at a distance r athwartships of the compass in its horizontal plane are

$$a = -(M/Hr^3) = -(ma^3/r^3)$$

$$e = +(2M/Hr^3) = +(2ma^3/r^3)$$

$$k = -(M/Hr^3) = -(ma^3/r^3)$$

$$\lambda D = [(a - e)/2] = -(3ma^3/2r^3)$$

Usually two spheres are placed on opposite sides of the compass at equal distances. If their mutual interaction is neglected, the effects will be twice those given above, so that the contributions to the coefficients will be

$$a = -(2ma^3/r^3)$$

$$e = +(4ma^3/r^3)$$

$$k = -(2ma^3/r^3)$$

$$\lambda D = -(3ma^3/r^3)$$

The curves of (m/m_0) show the corrective effect of a hollow sphere relative to a solid sphere of the same material. The curves of m show the corrective effect of a hollow sphere relative to a sphere of infinite permeability. The moment of a sphere or spherical shell of infinite permeability is Ha^3 regardless of the thickness.

This work was done at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington while engaged in work under contract NObs-24204 for the Navy Department.

References

[1] Peter Barlow, An essay on magnetic attractions, London, 1820, pp. 44-45. (There is a second edition, London, 1823 and 1824.)

[2] Siméon Denis Poisson, Mémoire sur la théorie du magnétisme, Mémoires (de l'Adadémie Royale des Sciences) de l'Institut de France, Années 1821 et 1882. Tome V, 1826, pp. 247 ff. Lu à l'Académie Royale des Sciences le 2 février 1824.

[3] Arthur Gordon Webster, The theory of electricity and magnetism, London, 1897, p. 378.

[4] E. Mascart and J. Joubert, A treatise on electricity and magnetism, translated by E. Atkinson, 1, London, 1883, p. 370.

[5] D. W. Dye, Use of stalloy rings for magnetic shielding purposes, J. Sci. Inst., 3, 65-69 (1925).

[6] Admiralty manual for the deviations of the compass, seventh ed., 1901 (revised 1920).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington 15, D. C., July 15, 1947

NOTES

(See also pages 341, 355, 367, and 412)

Mrs. *E. Kidson* of New Zealand, presented to the Royal Meteorological Society, at its meeting at Oxford on August 7, 1946, a printed copy of her late husband's journals covering the period during which as Director he was engaged in establishing the New Zealand Magnetic Survey.

Announcement has been made of the retirement of Dr. *Joaquin Gallo* as Director of the Tacubaya Observatory in Mexico. Dr. *Guido Munch* is now in charge of the Observatory.

During October 21, 1946, to April 11, 1947, *A. P. Bondarenko* of the Kiev Institute of Geology, Ukraine, was a Guest Investigator at the Department of Terrestrial Magnetism, Carnegie Institution of Washington (DTM CIW).

J. W. Graham of Johns Hopkins University, following appointment as a Fellow for the period March 1, 1947, to July 31, 1948, with *Thomas Murphy*, left early in August, 1947, for the New England and Middle Atlantic states to obtain specimens of clay, sedimentary, metamorphosed, and igneous rocks to be used in paleomagnetic research at DTM CIW.

Professor *D. R. Inglis* of Johns Hopkins University has been spending one or two days each week since July 1, 1946, working with Dr. *N. P. Heydenburg* in the high-voltage laboratory at DTM CIW.

Dr. *T. H. Pi* of National Central University, Nanking, China, who has been working from April 7, 1947, with Dr. *Roberts* in the cyclotron-building and also with Dr. *Heydenburg* in the high-voltage laboratory at DTM CIW, returned late in August to China.

Miss *Juliette Roquet* of Institute de Physique du Globe of the University of Paris continued work through July 31, 1947, with Dr. *Ellis A. Johnson* on clay and varve specimens and measurements. She is now taking a trip to the west coast and on returning in September will join Dr. *Maurice Ewing's* group at Columbia University doing special mathematical work somewhat similar to the work she did at DTM CIW. Miss Roquet will return to France early in 1948.

J.E.Sreb of the Applied Physics Laboratory, Johns Hopkins University, has been engaged for part time from March 31, 1947, at DTM CIW with Dr. *R. B. Roberts* in the cyclotron-building.

Captain *L. V. Berkner* retired from his assignment, since July 1, 1946, as Executive Secretary with the Joint Research and Development Board, on July 1, 1947. After a vacation he will resume his duties from September, 1947, in charge of the Division of Upper Atmospheric Physics at DTM CIW.

J. Doak joined the staff of DTM CIW as Laboratory Assistant, April 14, 1947.

CRITICAL SURVEY OF RECENT THEORETICAL WORK ON THE IONOSPHERE

By A. Pande*

Introduction

In recent years a number of theoretical papers have been published on the ionosphere by workers all over the world. From time to time reviews of the theoretical, as well as practical, works have been written by eminent workers [see 1, 2, 3, 4 of "References" at end of paper] in the form of reports. After a study of these papers one finds a certain number of inconsistencies in the various results and assumptions. The purpose of this article is to point out these facts in detail in the form of a review and draw the attention of the workers in this field for solving some of the fundamental problems without which the theoretical work is much handicapped at the present stage.

The following symbols have been used in this paper:

I = Rate of ion-production
I_o = Maximum ion-production
h_o = Height at which ion-production is maximum
h' = Height of layer
H' = Scale height
$z = [(h' - h_0)/H']$
K = Boltzman's constant
T = Temperature, ° absolute
m' = Mean molecular mass
g = Acceleration due to gravity
α = Recombination-coefficient (general)
α_e = Recombination-coefficient of electrons and positive ions and neutral molecules
α_1 = Recombination-coefficient of electrons and neutral molecules
α' = Effective recombination-coefficient
$R = [(a + h')/H']$, a parameter
a = Radius of Earth
t = Time in seconds
N = Ionic density (general)
N_{max} = Maximum ionic density
N_e = No. electrons per cc
N_- = No. negative ions per cc
N_o = No. oxygen atoms per cc
N_+ = No. positive ions per cc
n = No. molecules per cc
n_o = No. neutral molecules per cc
λ' = Ratio negative ions to electrons
χ = Sun's zenith-angle
β = Molecular absorption-coefficient
E = Intensity solar radiation
W = Ionization-potential
P = Pressure of gases
z' = Nuclear charge
h = Planck's constant
e = Electronic charge
m = Electronic mass
v = Upper frequency-limit ultraviolet radiation

*Of Scientific and Industrial Research, Delhi, India; now with Radio Corporation of America, RCA Laboratories Division, Princeton, New Jersey.

v_o = Lower frequency-limit ultraviolet radiation
$p_o^2 = (4\pi N_e^2/m)$
$p_L = (eHL/mc)$
p_h = Larmor frequency = (eh/mc)
$p_T = (eHt/mc)$
p = Electric wave angular velocity
p_c = Critical angular frequency
μ = Refractive index of medium
k = Absorption-coefficient of medium
ν = Collisional frequency of electrons with gas molecules
H = Total magnetic field Earth
H_L = Longitudinal component of Earth's magnetic field
H_T = Transverse component of Earth's magnetic field
H_y, Hz = Magnetic vectors
l = Lorentz polarization term
$y_T = (pt/p)$
$y_L = (p_L/p)$
$z'' = (v/p)$
S = Any function whose differential coefficient is complex
λ = Wave-length of electromagnetic waves
f = Frequency of electromagnetic waves
φ = Function of λ
U = Group-velocity
γ = Attachment-coefficient
k = A constant
b = Twice intermolecular distance
C = A constant = -0.577
$fo^2 = (Ne^2/\pi m)$
$F(f) = -\log \rho$
P = Reflection-coefficient
Q = Total elastic cross-section
N_s = Electronic density summer
N_w = Electronic density winter
T_s = Temperature ionosphere summer
T_w = Temperature ionosphere winter
τ_s = Electronic temperature of ionosphere summer
τ_w = Electronic temperature of ionosphere winter
θ = Co-latitude of place
δ = Sun's declination

(I) *Determination of ionization-density*

In a series of well known papers Chapman [5, 6, 7] has calculated the ionization-densities of the upper atmospheric layers on the assumption that density of atmosphere varies exponentially with height and ionization is caused by absorption of ultra-violet light only. He further assumes that ionized products recombine with one another and do not diffuse away. He derives the following equations (1) and (2).

$$I = I_o \exp.(1 - z - e^{-z} \sec \chi) \quad \text{.......................(1)}$$

$$\frac{dN}{dt} = I - \alpha N^2 \quad \text{.................................(2)}$$

The equation (1) gives the rate of ion-production at any height and (2) gives the ionization-density corresponding to a certain height and time. Chapman has solved the differential equation (2) and has drawn a number

of curves showing the variation of ionization-density at different heights and times of the day and night.

In another two papers Millington [8, 9] has drawn a number of charts giving contour-lines of equal ionic density over the surface of Earth for winter, equinox, and summer conditions. These curves are more useful from the practical point of view, though the calculations involved are tedious and the value of the parameter R is arbitrary and uncertain. He has put $R = [a + h')/H']$. The value of H' varies considerably depending upon temperature, composition, and pressure of the gases present in the upper atmosphere. Its value ranges from 8.4 km to 112 km and therefore R fluctuates from 770 to 58. Millington has taken $R = 150$ but gives no theoretical basis for this.

Chapman's simple theory does not take into consideration the absorption of several spectral bands of ultra-violet light radiation having different absorption-coefficients nor the various other phenomena which have been mentioned by Chapman and Bartels [10]. Hence the variation of ionic density with height and time as derived from Chapman's theory holds good for E- and $F1$-layers only as verified experimentally by a number of workers [11, 12, 13]. But the theory does not hold good when applied to $F2$-layer which has properties quite different from those of the E- and $F1$-layers. Instead of one maximum at noon as for E- and $F1$-layers there are two daily maxima, one before noon and the other after noon. Similarly instead of one yearly maximum in summer like E and $F1$ it has two maxima, one in March and the other in October and November.

Many theories have been put forward to explain this anomalous behavior of the $F2$-layer. Kirby, Berkner, and Stuart [14] suggest that ionization in $F2$ does not become greater in summer than in winter but, owing to more intense absorption of the reflected waves in summer than in winter, the critical-frequency determinations are spurious and echoes are lost by absorption at a frequency very much less than the critical frequency. This theory seems to be erroneous in view of the observations of Berkner and Wells [15] at Huancayo, which show the same morning and afternoon maxima in more pronounced form. Appleton and Naismith [16*a*] think that $F2$-ionization in summer is about the same as in winter and at noon there is some cause to depress the critical frequency when the Sun is at its maximum altitude. They hold the view that this apparent anomaly is due to the fact that the molecular temperature of the outermost layers of the upper atmosphere is greatly increased in summer with twofold results. First, the increase of temperature alters the value of H' and this reduces the density at which maximum ionization takes place. Second, the increased temperature causes the atmosphere to expand vertically reducing the maximum ionic density considerably. On this assumption they estimated the temperature of the upper atmosphere

($F2$-layer) as 1200° T at summer noon. This point will be discussed in detail later on. Appleton [16b] has given a quantitative expression to this supposition and suggests that instead of equation (2) the following equation (3) should be used for the $F2$-region.

$$\frac{dN}{dt} = I - \frac{N}{T}\frac{dT}{dt} - \alpha N^2 \quad \text{.........................(3)}$$

In equation (3) the first term expresses the rate of ion-production by solar radiation, the second term expresses the rate of dilution or concentration of electrons, ions, and molecules resulting from thermal expansion or contraction due to solar heating. Appleton and Naismith have used this theory to explain the anomalous results qualitatively as observed in England. Equation (3) cannot be utilised for drawing ionization-density curves like equation (2) due to the fact that variation of T with time (t) is not known with any degree of accuracy. Hence equation (3) is not of much use for the present.

Mohler [17] has shown that outstanding seasonal anomaly of the $F2$-layer can be entirely accounted for by the seasonal variation in pressure. For temperature-equilibrium between oxygen atoms, electrons, and ions, the ratio of negative ions to electrons is given by Saha's equation as in (4) in which electron-affirmity of 2.2 volts has been used instead of ionization-potential.

$$\frac{N_e N_o}{N_-} = \frac{N_o}{\lambda'} = 6.05 \times 10^5 T^{3/2} e^{-2.2\times 11600/T} \text{..................(4)}$$

Variations in pressure would change the value of λ' and hence the electronic density. At a partial pressure of 4×10^{-8} mm, λ' would become unity at 960° T (absolute degrees) and at this temperature a change of ten per cent in T would give tenfold change in λ'. Hence in order to explain the anomalous behavior of the $F2$-layer it is not necessary to assume such high temperature-ratio as was done by Appleton and Naismith. This point will be referred to again.

Another theoretical approach to the problem of calculating ionization-density has been made by Hulburt [18, 19, 20, 21, 22]. Like Chapman, he also assumes that ultra-violet light is the main source of ionization and calculates the ionizing effects of these rays on atmospheric gases. He further assumes that nitrogen and oxygen molecules are dissociated into atoms above 200 km. He derives the following equation (5).

$$N^2 = n(\beta/\alpha)(E/W) \exp. (-\beta n/P \cos \chi) \quad \text{..................(5)}$$

The absorption-coefficient for light in the continuum below the series limit is that deduced by Kramers [23] from classical theory assuming a special law of electron-capture. β and α are given in equations (6) and (7).

$$\beta = \frac{16\pi^2}{3\sqrt{3}} \frac{z'^4 e^2 c^5}{h} \frac{h\nu_o}{h\nu^3} \text{..................................(6)}$$

$$\alpha = 1.02 \times 10^{-11} z'^2 / T^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

From the equations (5), (6), and (7) a number of curves showing the variation of electronic density with height have been drawn. These curves are in good agreement with observations of the E- and $F1$-layers only. For $F2$, Hulburt gets the value of maximum electronic density as 9.5×10^5 for a height of 272 km for nitrogen and 2×10^6 for oxygen, corresponding to a height of 228 km. By taking summation of oxygen and nitrogen curves Hulburt gets the maximum value of electronic density as 1.8×10^6 at about 240 km, which is above the summer noon values for $F2$ as found experimentally at Washington, Watheroo, and Huancayo.

Like Appleton and Naismith he also explains this by assuming that heating of the upper atmosphere takes place giving rise to an expansion of the $F2$-layer which reduces the electronic density. Hulburt does not take into consideration the selective absorption of ultra-violet radiation by the various constituents of the upper atmosphere nor does he consider the variation of ionization due to temperature-gradient with height. All his calculations have been done for a constant temperature of 360° T. He further supposes that above 200 km oxygen and nitrogen are in atomic states. The value of absorption-coefficient as taken from Kramer's equation (6) can scarcely claim an accuracy better than an order of magnitude. The value of α has been derived from that of β, hence it has got the same uncertainties and errors and therefore Hulburt's results also do not give us ionization-densities of the $F2$ layer (via which most of short-wave communication takes place) more correctly than that obtained from equation (2). However, his equations if properly developed can give accurate results for determining the electronic densities of the $F2$-layer.

Eckersley [24] has tried to explain the anomalous behavior of the $F2$-layer on the assumption that there is a biennial component number. This is a speculative hypothesis and for its support there is nothing except some statistical data. Hetchel [25] has calculated the daily course of electron-temperature to be different from the gas temperature of the atmosphere. He concludes that ion-production cannot be determined definitely from the daily course of electron-concentration and suggests that only a lower limit can be derived.

Starting from Saha's [26] thermal ionization-theory and its extension by Woltjer [27], Pannekoek [28] developed a method of computing upper atmospheric ionization. It has been recently shown by Saha and Rai [29] that Chapman's theory if it were properly developed would have led to the same results as those of Pannekoek. Milne [30] has given an easier deduction of Woltjer's formula based on kinetic-theory considerations as the thermodynamical derivations from the latter's formula are rather too complicated. Bhar [31] has utilised Milne's deductions and computed the

ionization of the upper atmosphere according to Pannekoek's method on the assumption that atmosphere below 100 km consists mainly of molecular nitrogen and oxygen, and that above this level it contains molecular nitrogen and atomic oxygen and that there is a layer of transition between the two at about 100 to 130 km. He has made the following assumptions:

(*a*) Dissociation of oxygen molecules at about 130 km is almost complete as given by Majumdar [32].

(*b*) Density of oxygen molecules at 80 km is 1.6×10 according to Mitra and Rakshit [33].

(*c*) Values of absorption-coefficient for molecular oxygen and nitrogen are those given by Kramer's equation and that of oxygen atom that given by Saha and Rai's equation.

(*d*) Temperature of the upper atmosphere above 130 km is 600° *T*.

(*e*) No recombination, attachment, or detachment takes place and the electronic density is dependent only on the number of ions produced by molecular nitrogen, molecular oxygen, and atomic oxygen.

Though this is a new method of attack it has a number of discrepancies. The assumption (*a*) is taken from Majumdar, which, as will be shown later on, is a rough approximation only. The factor (*b*) suffers from the same uncertainties as (*a*) and will be taken up again. The applicability of assumption (*c*) to ionospheric or astrophysical problems is unjustified as shown experimentally by Page [34] and theoretically by Saha and Rai [29]. The factor (*d*) is very important because it governs the dissociation and composition of the upper atmosphere. Hence assuming arbitrary fixed values for the region beyond 130 km is likely to introduce serious errors; as we know now that at the level of 300 km the temperature of the upper atmosphere is of the order of 1000° *T* [35] and sometimes as high as 3300° *T* [36]. Finally the phenomena of recombination, attachment, and detachment must be taken into consideration because the ions that are formed by the photo ionization of molecular oxygen, molecular nitrogen and atomic oxygen recombine with positive ions and neutral molecules and the resulting ions only contribute to the electronic density with which we are concerned in ionospheric investigations. Thus it seems evident that none of the calculations made so far account satisfactorily for the ionization-density of the *F*2-layer, much less its variation with height and time.

(II) *The propagation of electromagnetic waves through ionosphere*

The theory of propagation of light-waves through a system of molecules was first given by Lorentz [37]. This theory was applied to the radio-wave propagation through a medium (containing charged particles) in the presence of magnetic field whose direction was parallel and per-

pendicular to the direction of propagation of electromagnetic waves. This Lorentz theory is known as magneto-ionic theory. Eccles [38] and Larmor [39] had applied the original theory to radio-wave propagation but they had not taken magnetic field into consideration. The applicability of Lorentz theory to the explanation of phenomena connected with the propagation of radio waves through the ionosphere was first suggested by Appleton [40] and Nichols and Schelleng [41]. Lorentz treatment was extended for a general case at any angle of inclination of waves to the magnetic field of the Earth almost simultaneously and independently by Appleton [42], Breit [43], Hartree [44], and Goldstein [45]. The formulas obtained by Appleton and Hartree were almost the same, and hence the equations for dispersion and polarization are better known by their names. Neglecting the Lorentz polarization-term after Darwin [46] the equations for dispersion and for polarization are as given in (8) and (9).

For dispersion

$$c^2q^2 = \left(\mu - \frac{ick}{p}\right)^2 = 1$$

$$- \frac{2p_o^2}{2(p^2 - ip\nu) - \dfrac{p^2p_T^2}{p^2 - p_o^2 - ip\nu} \mp \sqrt{\dfrac{p^4p_T^4}{(p^2 - p_o^2 - ip\nu)^2} + 4p^3p_L^2}} \quad \text{.....(8)}$$

For polarization

$$\frac{H_y}{H_z} = \frac{ipp_L(c^2q^2 - 1)}{p_o^2 + (ip\nu - p^2)(1 - c^2q^2)} \quad \text{.......................(9)}$$

Equation (8) gives the relation between incident wave-frequency and the refraction- and absorption-indices for the ionosphere for various split components of the wave whereas equation (9) gives their states of polarizations. In general in equation (8) the positive sign refers to ordinary and the negative to extraordinary ray. Booker [47] has shown that ordinary wave, for $(p_o/p) > [1/(1 - l)]$, is given by positive or negative sign as (pc/v) is less or greater than unity. The extraordinary component is given by the reverse sign. Toshniwal, disagreeing with Booker's calculations, has shown that the absorption of the extraordinary wave is greater than that of the ordinary one.

Mitra and Roy [49] have pointed out an interesting feature in the formula for ionospheric dispersion. They have shown that the formula can yield values of dielectric constant of an ionised medium greater than, equal to, or less than unity depending upon the degree of ionization, collisional, and wave frequencies. They hold the view that the value greater than unity is only an outcome of the complete dispersion-formula. Khastgir and Bose [50] have deduced the following conditions

under which the dielectric constant may have different values: $\mu < 1$ for $p > 2.8 \times 10^4\sqrt{N}$ and $\mu > 1$ for $p < 2.8 \times 10^4\sqrt{N}$, when $v > p^2/\sqrt{p_o^2 - p^2}$. They have also shown that experimental condition to verify this formula is such that dispersion-formula alone cannot explain the anomaly.

The conditions of reflection of ordinary and extraordinary rays are obtained by taking the positive and negative signs before the radical (subject to the above condition) and putting $c^2q^2 = 0$. These conditions as derived from equation (8) and are given by equation (10).

$$\left.\begin{array}{l}(a)\ \text{For ordinary rays: } p^2 = p_o^2 \\ (b \text{ and } c)\ \text{For extraordinary rays: } p_o^2 = p^2 \pm pp_h\end{array}\right\} \quad \ldots\ldots\ldots (10)$$

The refractive index is a complex quantity and depends upon the collisional frequency and electronic concentration, hence it can never be equal to zero. Therefore the conditions obtained by putting $c^2q^2 = 0$, cannot give the complete picture of reflection. To meet this difficulty Booker [51] tried to formulate another criterion. He investigated (by methods of approximation) the general problem in which both ionization-density and collisional frequency vary with height and derived the absorption suffered by the waves in the deviating and non-deviating regions—according to him in the deviating region $\mu = 0$ and in the non-deviating region $\mu = 1$. His results are not of much practical utility as he has assumed that collisional frequency varies with height in a certain hypothetical way for which there is no theoretical justification.

The equation of Appleton and Hartree is applicable for investigating vertical propagation only. Booker [52] in another paper has generalised this equation to include the cases of oblique-ray propagation which are the usual features met with during long-distance, short-wave communications. Rai [53] has shown that neglecting collisional friction, a better criterion of reflection is obtained if group-velocity instead of refractive index is assumed to be zero. He obtained the following four conditions of reflection in equations (11).

$$\left.\begin{array}{l}(a)\ \text{For ordinary ray } p_o^2 = p^2 \\ (b \text{ and } c)\ \text{For extraordinary ray } p_o^2 = p^2 \pm pp_h \\ (d)\ \text{For extraordinary ray } p_o^2 = p(p^2 - p_L^2)/(p^2 - p_h^2)\end{array}\right\} \quad \ldots\ldots\ldots (11)$$

This extra condition of reflection (d) was experimentally verified by Pant and Bajpai [54], Toshniwal [55], Harang [56], and Jouaust [57]. Assuming that considerable reflection of radio waves takes place in the ionosphere at the point where $d\mu/dN = \infty$, Bajpai [58] derived the same

four conditions of reflection (as obtained by Rai from the equation of Appleton and Hartree). Theories on propagation of radio waves in the entire range of frequencies together with the applicable limit of geometrical optics to radio-wave propagation have been discussed in detail by Namba [59]. He has derived the well known "ioconal equation" of geometrical optics and also the condition expressing the limit of applicability of the theory. The equation is

$$\Sigma\left(\frac{\partial\varphi}{\partial x}\right)^2 = \frac{f^2b^2}{e^2} = \frac{1}{\lambda^2} \qquad \text{.........................(12)}$$

and the limit is that

$$2\pi j\Delta\varphi \ll 4\pi^2\Sigma\left(\frac{\partial\varphi}{\partial x}\right)^2$$

Saha and Rai [60] thought that ray-treatment alone could not completely explain the phenomena of reflection and so they applied wave-mechanics for the solution of propagation phenomena through the atmosphere. They arrived at nearly the same formula as derived by Appleton and Hartree. They showed that contrary to the usual assumption (used in ray-treatment) that at the point where refractive index falls to zero complete reflection takes place, there may be considerable penetration by the wave of the ionosphere even when the thickness of the layer amounts to several km.

Phenomena of total reflection of electromagnetic waves, including damping due to collision, have been discussed by Bose [61] from the microscopic equations of Lorentz. He derived the following equation (13) for the critical frequency for total reflection.

$$\left(\frac{ds}{dt}\right)^2 + \nu\left(\frac{ds}{dt}\right) + \frac{Ne^2}{m} = 0 \text{.........................(13)}$$

From the above equation he concludes that the wave totally reflected will have the form

$$\text{exp. } (-vt/2 \pm i\sqrt{p^2} - v^2/4)$$

and the condition of reflection would be given by the following equation

$$\left(\frac{ds}{dt}\right) = --v/2 \pm i\sqrt{p_o^2 - v^2/4} \text{.........................(14)}$$

Hence

$$p_c^2 = Ne^2/m - v^2/4 \qquad \text{.........................(15)}$$

Putting $v = 0$ Bose has obtained conditions of reflections similar to those of Appleton and Hartree (when refractive index equals zero) and of Rai and Bajpai (when group-velocity equals zero). For delineating the pro-

pagation of electromagnetic waves through the ionosphere where collisional frequency and electronic density are slowly varying with height, Bose's equations cannot be used to give any new dispersion-curves because they do not give any extra condition of reflection as shown by Rai [62]. Moreover, the assumptions made in deriving these conditions of reflection are of doubtful nature as pointed out by Saha and Mathur [63] in a subsequent paper. So for the present the problem seems to remain unsolved.

Mary Taylor [64] has drawn exhaustive dispersion- and polarization-curves from the Appleton-Hartree formula for zero absorption. She has drawn another series of curves from the same formula taking arbitrary values of the collisional frequencies, for example, $\nu = 10^5$, 10^6, 10^7, etc. Similar curves have been drawn by Bailey [66], Martyn [67], Goubau [68], and Ghosh [69]. From Rai's equations another type of curves has been drawn by Goubau [70] and also by Bajpai and Mathur [71] depicting the variation of group-velocity with electronic density. Rai's equation which is derived from Rayleigh's theorem does not take into consideration damping due to collisional frequency. Hence the group-velocity curves as drawn from this equation only show the fourth condition of reflection. The group-velocity curves if drawn from more complete formula taking collision into account would really be of great value in elucidating the propagation phenomena of radio waves in the ionosphere.

A suggestion by Saha and Mathur [63] was made to tackle this problem. They pointed out that μ^2-values should be plotted against corresponding theoretically calculated values of ν and N. The value of N according to them can be calculated from Chapman's simple theory and that of ν from kinetic gas theory by assuming T to be constant or varying according to some assumed law. Though it is an excellent suggestion, it has a number of difficulties which must be solved beforehand. First, as pointed out earlier, Chapman's theory cannot be utilised for calculating N with height for the $F2$-layer unless the drawbacks of this theory are removed and some new theoretical calculations are made to find out the variation of the $F2$ ionic density with height. It will be shown later on that the theoretical value of N cannot be calculated with much accuracy unless the temperature and its gradient with height and time are known exactly. As there is a lot of uncertainty about the temperature of the $F2$-layer, the problem of drawing dispersion- and polarization-curves including collisional frequency seems to remain still unsolved.

(III) *The dissociation, recombination-, attachment-, and detachment-processes in the ionosphere*

The conventional theory of ionization is that electrons are produced by dissociation of gas molecules due to photo-ionization by solar radia-

tion. These electrons are supposed to disappear by recombination at a rate proportional to N^2 and different layers of ionization are usually ascribed to different absorption-processes. There are maxima of ionization at 250 km due to atomic oxygen and at 160 km due to molecular nitrogen and at 100 km due to molecular oxygen. These are known as the $F2$-, $F1$-, and E-layers, respectively. The limits of wave-length ranges absorbed by the gases have been obtained from spectroscopic data and for ultra-violet light these have been collected by Saha [72] and Chapman and Price [73]. From these limits of absorption, it has been shown by Bhar [31] that the $F2$-region owes its origin to photo-ionization of atomic oxygen (13.55 e-v), the $F1$ to that of molecular nitrogen at its second ionization potential (18.67 e-v), and the E to the dissociation of molecular oxygen in atomic state.

According to Hulburt [4] the temperature of the upper atmosphere (above 160 km) rises about 50° T per hour during the day owing to the absorption of solar ultra-violet light by molecular oxygen in the region 850 to 910 Å; wave-lengths below 850 Å are absorbed by nitrogen. Hence the temperature becomes so high that molecular oxygen and possibly molecular nitrogen are dissociated into atoms. Wulf and Deming [72] have shown that dissociation of oxygen must be nearly complete above 100 km and estimate the number of oxygen atoms at about 100 km as $10^{12}/cc$. Majundar [75] has shown that at a level of 130 to 167 km complete dissociation of oxygen molecules takes place. This result has been obtained on the assumption that temperature at this height is 300° T and the molecular weight of the atmosphere is the same as the average mass of nitrogen molecules. No attempts seem to have been made by these workers to find out on what factors depends the dissociation of molecular oxygen, molecular nitrogen, and atomic oxygen which are responsible for the stratification of E-, $F1$-, and $F2$-layers. Moreover, as the temperature of the upper atmosphere has been assumed to be constant by these workers, the part played by temperature in the phenomena of dissociation seems to have been ignored by them. However, these calculations give an idea of the height at which the dissociation of molecular oxygen is completed and this knowledge is of much use in calculating the density of the constituent gases in the ionosphere. Similar attempts to find out the levels at which possible dissociation of nitrogen molecules to nitrogen atoms will take place will be of some interest.

Chapman [5] was first to consider the production of ions and electrons from dissociation of gas molecules by the absorption of ultra-violet radiation from the Sun. Assuming that recombination of electrons with neutral gas molecules is proportional to the square of the electronic density, he derived the differential equation (2). This theory, as we know, gives a very satisfactory explanation of the daily and annual variation of the E-

and $F1$-layers, but fails to explain the behavior of the $F2$-layer. Bradbury [76] points out that its apparently erratic behavior can be characterized by a very slow rate of re-combination. Eckersley [77] and Appleton and Naismith have shown that electrons disappear by a process of recombination with positively charged ions in the E- and F-regions, though formerly the latter authors held the view that electrons disappear mainly by attachment to neutral particles. Despite the success of the recombination-theory to the E- and $F1$-layers, it is not possible to accept it as complete representation of facts particularly for the case of the $F2$-layer. Martyn and Pulley [35] have suggested that during recombination detachment of electrons also takes place, otherwise the existence of ionization of the F-region in the night cannot be explained. According to them the electronic density in the F-layer is the equilibrium-value (especially after sunset) when the number of electrons becoming attached or recombined equals the number set free during chemical recombination and particularly during the recombination of oxygen atoms to oxygen molecules. The dissociation-potential of oxygen is 6.5 e-v, while the electron-affinity of atomic oxygen is two to three volts so that electrons are set free with about four volts energy. On this assumption these authors have explained the formation of the E- and F-layers in the night. They also point out that this supposition explains the anomalous behavior of the $F2$-layer for which Appleton and Naismith had to assume very large seasonal variations in ionospheric temperatures.

The relative probabilities of dissociation, recombination, attachment, and detachment of electrons in the E- and F-layers have been worked out by Massey [78]. He gets the following results for E-layer: (*a*) Rate of attachment per electron, 0.07/sec; (*b*) rate of detachment per negative ion, 10^3/sec; (*c*) rate of recombination per electron, 2×10^5/sec; (*d*) collisional frequency of electrons, 2×10^5/sec. The important result which emerges from these numerical values is that the rate of recombination is much slower than that of either attachment or detachment. Massey favors the view that electrons disappear both by recombination and attachment and suggests that instead of Chapman's differential equation (2) the following equation

$$\frac{dN}{dt} = I - \gamma n_n N \qquad (16)$$

may be used for calculating ionization-density. Similarly for the F-region, Massey finds that recombination-coefficient is 216×10^5 which is rather high and contradictory to observations. To overcome this difficulty, he supposes that density of positive ions is not much greater than that of electrons. The assumptions made by Massey during his calculations are only approximately correct. Instead of the mean dipole moment of

molecular or atomic oxygen that of chlorine has been taken and also the temperature has been taken to be constant at 680° T. Hence the values obtained by him are correct to the order of magnitude only. Further work on these lines may be of great use in exactly calculating the ionization-densities of the E- and F-layers.

Nature of recombinational processes have been discussed by Mohler [17]. Like Massey, he holds the view that electrons disappear both by recombination and attachment and the rate of recombination decreases rapidly with decreasing pressure above the $F1$-layer. A necessary consequence of this is that the level of maximum electronic density is far above the level where the rate of ion-production is a maximum. This supports Bradbury's suggestion that the $F1$- and $F2$-layers are formed by the same ionization-process with the maximum production of ions at $F1$-level. For $F2$-layer Mohler gets the values of recombination- and attachment-coefficients as 2×10^{-12} and 6×10^{-5}, respectively. These values are correct to the order of magnitude only as his calculations have been made on the assumption that the temperature of the $F2$-layer is constant at 680° T and the value of scale height (H') is 36 km. Both these assumptions are vague and incorrect and therefore the values obtained are not very exact. However, his calculations have given an excellent quantitative explanation of the anomalous behavior of the $F2$-layer as shown earlier.

Bates, Buckingham, Massey, and Unwin [79] point out that the recombination of electron to neutral molecules or atoms to form negative ions is as important as the recombination of electrons with positive ions to form neutral molecules. Instead of the usual recombination-coefficient α they suggest that effective recombination-coefficient α' should be taken into consideration which is given as equation (17).

$$\alpha' = \alpha_e + \lambda'\alpha_i \quad \text{.............................(17)}$$

They find that λ' is equal to 100 to 1000 for the E-layer and equal to 10 for the F-layer. The value of α_i is 2×10^{-11} per cc per sec.

According to Appleton, for $\lambda' = 100$ the effective recombination-coefficient should be equal to 10^{-8}, which is rather high as compared with the usual value of recombination-coefficient (α) as used by Chapman for calculating the ionization-density of the ionosphere. In view of the fact that by both the processes of recombination electrons are removed and it is only the resultant electronic density which matters for electromagnetic wave-propagation, this hypothesis is much nearer the actual facts, and values of effective recombination-coefficient should be taken into consideration for calculating the electronic density of the E- and F-layers.

The variation of the recombination-coefficient with temperature has

been theoretically dealt with by Chapman utilising Milne's theory. According to the former, the recombination-coefficient varies inversely as square root of temperature and the value of this recombination-coefficient between electrons and oxygen atoms is equal to 3.2×10^{-10} at a temperature of 400° T and 2.3×10^{10} at 600° T. These values are in fairly good agreement with experimental values of Eckersley [82] and Appleton [83] obtained from oblique- and vertical-ray measurements, respectively. As given in equation (7) Hulburt also has calculated the values of recombination-coefficient from Saha's theory of ionization of a gas in photoelectric equilibrium. He obtains the following values: $\alpha = 3.4 \times 10^{-11}$ for oxygen corresponding to 360° T and $\alpha = 2.6 \times 10^{-11}$ for nitrogen corresponding to the same temperature. Bates, Massey, Buckingham, and Unwin [79] have also calculated the variation of radiative recombination-coefficients for oxygen between the range 220° T to 8000° T and if this is modified to take into account only two-body collisions and the values of effective recombination-coefficient calculated therefrom, it will be one of the most dependable data for calculating the electronic density of the F-layer.

(IV) *The determination of electron collisional frequencies in the ionosphere*

Determination of electron collisional frequency, especially its gradient with height, will be of great use in calculating the temperature of the upper atmosphere. It will also be very helpful in depicting the dispersion-curves of radio-wave propagation in the ionosphere. So far little theoretical work has been done though there are experimental observations by Eckersley [84], Farmer and Ratcliffe [85], and Appleton [86]. As shown earlier, Massey [78] has calculated the collisional frequencies of the E- and F-layers from considerations of recombination, attachment, and detachment. His values are correct to the order of magnitude only. Applying quantum mechanics Miltra, Ray, and Ghosh [87] have calculated the cross-section of atomic oxygen for elastic value of collisional frequency for this layer as 2.4×10^3 sec on the assumption that temperature of the layer is 1000° T after Martyn and Pulley [35] and density of oxygen is 4×10^9 atoms/cc as given by Mitra and Rakshit [33]. Though the value of collisional frequency for the F-layer as obtained by them agrees fairly well with the mean of experimental results, their assumption of the temperature of the layer as 1000° T, according to Martyn and Pulley, and of temperatures after Mitra and Rakshit [33] are not independent data. The former authors have calculated the temperature of the F-layer from experimental values of collisional frequencies of the E- and F-layers and the use of this temperature for calculating collisional frequency back cannot be justified. Similarly Mitra and Rakshit have used arbitrary values of the temperature for the upper atmosphere while cal-

culating the density and composition of its constituents and therefore these values cannot be utilised for calculating collisional frequency.

Considering an ionospheric model consisting of electrons and ions only, Majumdar [88] has discussed the phenomena of dispersion, absorption and polarisation and has calculated the collisional frequency of electrons with ions for the E- and F-layers. He deduces the following equation (18).

$$\nu = \frac{1.8z'^2}{T^{3/2}} \{\log(kT \times 6.63 \times 10^{27} b^2) - C - 1\} \quad \text{.........(18)}$$

From the above equation taking N_e as 10^5 for the E and 10^6 for the F-layer, he gets the values of collisional frequency between electrons and positive ions as 10^3/sec and 8×10^2/sec for the E- and F-layers, respectively. He obtains a high value of the collisional cross-section for the positive ion as he assumes that collision is taking place mainly between electrons and ions. No doubt the probability of elastic collision between electrons and ions is larger than that between electrons and neutral molecules, but the ratio cannot be so high as 10^6 as is demanded by Majumdar's hypothesis. Moreover, he also has used Martyn and Pulley's value of temperature of the F-layer which, as pointed out earlier, cannot be used for calculating the collisional frequencies. From the equation of de Groot [89] and Appleton [90], Pekeris [118] has derived another equation between electron collisional frequency, reflection-coefficient, and height of the layer and has suggested that this equation can be utilised for calculating the collisional frequency of the F-layer. His equation is as given in equation (19).

$$\nu = \frac{2c}{\pi f_o^2} \frac{d}{dh} \left[\int_0^f \frac{f^2 F(f)\, df}{\sqrt{f_o^2 - f^2}} \right] \quad \text{.........................(19)}$$

From this equation, value of the collisional frequency can be determined if we know the reflection-coefficients corresponding to a number of frequencies and also the variation of electronic density (n) with height of the layer (h'). If the reflection-coefficient with different frequencies is known, there are simpler methods of calculating collisional frequency. Moreover, as pointed out earlier, so far our knowledge about the variation of electronic density with height is very poor and uncertain for the $F2$-layer. Hence, this equation is not of much use for calculating the collisional frequency of this layer.

Fisk [91] has calculated the electric collisional cross-section of electrons with nitrogen and oxygen molecules by applying quantum mechanics for electron-velocities ranging from 0 to 40 e-v. His results have been verified experimentally by Ramsauer and Kollath [92] and Brüche [93]. From Fisk's calculations for the case of low electron-velocities, for example, 0.1 volt existing in the E-layer, it is found that the values of Q

(total elastic cross-section) for oxygen and nitrogen molecules are of the same order of magnitude as those found from the classical gas kinetic theory. Hence it becomes clear why the collisional frequency between electrons and neutral molecules as calculated by classical gas kinetic theory for the *E*-layer agrees so well with experimental results. This is not true for the *F*2-layer (where high electron-velocities are involved) and the collisional frequency calculated by taking gas kinetic cross-sections yields a value only 70 per cent of that obtained from quantum mechanical cross-sections. These points were referred to by Mitra, Ray, and Ghosh [87]. Ray [94] has also discussed the two types of collisions, one between electrons and positive ions and the other between electrons and neutral molecules, and concludes that as the collisional frequency between electrons and neutral molecules calculated from quantum mechanics agrees with the experimental observations, the absorption of radio waves (at least in the *E*-layer) is mainly due to elastic collisions between electrons and neutral molecules. It will be much better if both types of collisions are taken into consideration and attempts are made to calculate the effective collisional frequency. In all these calculations an accurate knowledge of temperature and its variation with height is almost essential. Alternatively the exact and independent data of electronic collisional frequency will give detailed and accurate information about various phenomena of the ionosphere.

(V) *The composition and temperature of the upper atmosphere*

In recent years the knowledge regarding the composition of the upper atmosphere has changed enormously. For a long time it was thought that the constituents of the upper atmosphere were hydrogen and helium. Works of Moore [95] and Helge Petersen [96] have shown the possibility of the existence of these elements at such heights owing to insufficient pull of gravity. The latest theoretical and practical results have revealed the existence of molecular nitrogen, molecular oxygen, atomic oxygen, water-vapor, and ozone. Presence of molecular nitrogen has been definitely established spectroscopically by Slipher [97]. The presence of molecular oxygen is supported by the observation of auroral spectrum. Wulf and Deming [74] have shown that the dissociation of oxygen must be nearly complete above 100 km and estimate the number of oxygen atoms as 10^{12}/cc as mentioned earlier. According to Majumdar [75], the photodissociation of molecular oxygen into atomic oxygen is almost complete near about 130 to 167 km by the absorption of bands beyond 1750 Å. The presence of atomic oxygen in large quantity is postulated by the presence of the well-known green-line first discovered by Maclennan and Shrum [98]. Atomic nitrogen is present only in small quantities as reported by Kaplan [99] and Bernard [100], who have identified the

line 3467 Å in the spectra of the light of the night sky and aurora. Water-vapor [101] and ozone are present in small quantities. The volume-concentration is only 1/6000. Few theoretical attempts have been made to find out the percentage of these constituents in the upper atmosphere. Chapman [102] was the first to assess theoretically the ratio of 0, 02, 03 in the upper atmosphere up to 120 km. His values, as he himself pointed out, are correct to a very rough degree. Mitra and Rakshit [33] have calculated the distribution of constituent gases and their pressures in the upper atmosphere. They have taken 100 km to be the datum-level and have assumed that the temperature starting from 300° T at 100 km rises linearly with height at the rate of 4° T/km reaching a value of 1100° at 300 km. As pointed out earlier, this is an arbitrary assumption and as most of the dissociation, recombination-attachment and detachment are taking place in this range, the temperature-gradient cannot be so regularly linear. If a better knowledge of temperature-gradient is applied, more accurate results are likely to be obtained. The density thus determined will be useful for the determination of electron-frequencies from the gas kinetic theory.

Of all the phenomena discussed so far, temperature seems to be the most fundamental in character. A number of workers have calculated the temperature of the ionosphere but no satisfactory solution seems to have been obtained. As stated earlier, from ionization-measurements of the $F2$-layer, Appleton and Naismith [16*a*] conclude that the mid-summer noon temperature should be 1200° T. This value they obtained from the following equation (20).

$$\frac{N_s}{N_w} = \sqrt{\frac{\sin(\theta + \delta)}{\sin(\theta - \delta)} \frac{T_w}{T_s} \left(\frac{\tau_s}{\tau_w}\right)^{1/2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(20)$$

Taking $N_s = N_w$, they get $T_s = 4T_w$ from equation (20). Assuming a moderate temperature of 300° T for winter noon after Angenheister [103], they conclude that mid-summer noon temperature should be 1200° T. The above equation has been derived from Chapman's theory and hence it cannot be utilised for the $F2$-layer as pointed out earlier. Moreover, the assumption of 300° T in winter noon according to Angenheister is not supported by theoretical or experimental facts. Martyn and Pulley have calculated the temperature of the F-layer from experimental values of collisional frequencies and get the maximum value of 1000° to 1200° T for summer noon. They do not agree with the large seasonal variations of temperature as assumed by Appleton and Naismith. Applying Planck's and Wien's laws of radiation, these authors have calculated that the change in temperature from winter to summer cannot be more than 25 per cent for T_s = 1000° T. Changes in temperature greater than this can only occur if the composition of the upper atmosphere undergoes profound

changes giving a much higher concentration of ozone, which is most improbable on theoretical grounds as shown by Chapman [104]. Mohler [17] has shown that seasonal variation of the $F2$ electronic density can be entirely accounted for by the seasonal variation of pressure only. He has shown that at a partial pressure of 4×10^{-8} mm, a change of ten per cent in temperature gives a tenfold change in the ratio of negative ions to electrons. Since the electronic density and height of the $F2$-layer depend on this ratio (which is extremely sensitive to temperature), slight changes in temperature can bring immense modification in the electronic density of the $F2$-layer. Hence large seasonal variations of temperature are not necessary to explain the anomalous behavior of the $F2$-layer.

Martyn and Pulley [35] have calculated the temperature of the F-layer on the assumption that electron collisional frequencies vary "linearly" between the E- and F-layers. This assumption is not supported by any theoretical or practical facts. On the contrary there are indirect evidences which suggest that between these levels the collisional frequencies should vary abruptly. Moreover, these authors do not calculate values of the temperature at heights greater than 250 km and hence the vertical temperature-gradient, which is so important, is not obtained by them. Godfrey and Price [36] have calculated the equilibrium-temperature of the ionosphere above 100 km taking into consideration the radiation and absorption by the constituents of the upper atmosphere. They get a temperature for day-time equilibrium as high as 2525° T and conclude that maximum temperature can be as high as 3300° T. In order to account for these high temperatures, they assume that large-scale convection-currents are responsible for bringing in warm air from the heated regions for which there seems to be no theoretical or practical evidence. Moreover these authors do not take into consideration the presence of molecular nitrogen and atomic oxygen, which are the most important constituents present at these heights as shown by the works of Majumdar [75] and Wulf and Deming [74]. Hence this method, though an independent one, needs recalculation in the light of the present state of our knowledge of the constituents of the upper atmosphere and their absorption- and radiation-coefficients.

Deb [105], from a number of phenomena of the upper atmosphere (for example, escape of helium, extension of auroral rays, absorption of radio waves, etc.), has deduced indirectly that the temperature of the F-region is of the order of 1000° to 1200° T. Penndorf [106] has calculated the temperature of the E- and F-layers from the equation $H' = KT/mg$ by taking values of H' for the E-layer from Appleton [107] and those for the F-layer from Pekeris. His values of temperature are rather low being 637° to 625° T. His method of calculating temperature by the above equation is open to serious criticism. He has taken the value of H' for the F-layer

from Pekeris, who has applied Chapman's simple theory for calculating the density of the F-layer. Moreover the values of H' are different as given by different workers. According to Booker and Seaton [108], H' is equal to 55 to 90 km and Appleton [109] puts it as 70 km. In view of all these uncertainties, it is not reliable to calculate the values of temperature from those of H'. Further he has used the results of Mitra and Rakshit [33] for the density of the constituents of the upper atmosphere. As pionted out earlier, the results of Mitra and Rakshit have been obtained on an arbitrary assumption of temperature, hence these derivations cannot be used back again to determine the temperature of the upper atmosphere.

All these theoretical calculations of temperature, therefore, seem to be interdependent and sometimes misleading. Hence the calculation of the temperature of the upper atmosphere, either by the method adopted by Godfrey and Price (including molecular nitrogen and atomic oxygen, which they have neglected) or by some independent spectroscopic method, will be of immense value for the theoretical study of the ionosphere, especially the $F2$-layer.

(VI) *Practical applications of the theoretical knowledge*

The present theoretical knowledge of ionosphere, especially the F-layer, is thus incomplete but it has helped the solutions of a number of practical problems of broadcasting, for example, prediction of maximum usable frequencies including skip-distance, calculations of the probable field-strength, and directivity of the aerial. Maximum usable frequencies for transmission of radio waves at normal incidence have been published for the first time in a report by the Committee on Radio Wave Propagation [110]. Methods of obtaining maximum usable frequencies at oblique incidence (which is the actual case met in short-wave, long-distance communications), taking into consideration the Earth's magnetic field and curvatures of the ionosphere and Earth, have been presented by N. Smith [111]. From Smith's calculations the graphs of maximum usable frequencies have been redrawn by Gilliland, Kirby, Smith, and Reymer [112]. Appleton and Beynon [113] have calculated the multiplying factors (for various skip-distances) for computing the maximum usable frequencies from the experimental data of critical frequencies obtained at normal incidence. Various attempts have been made to correlate the sunspot-numbers with maximum usable frequencies to find out some law governing their relationships and importance; among these are the works of Durkee [114], Kosikov and Gromov [115], Young and Hulburt [116]. Pande [117]. Taking into consideration the calculations of Smith, Appleton and Benyon has drawn a number of graphs of maximum usable frequencies up to the last sunspot minimum (1944). All these calculations of maximum usable frequencies give only approximate values.

For accurate determination of maximum usable frequencies, knowledge of electronic density of the ionosphere and its variation with latitude and time is almost essential. This becomes indispensable in long-distance communications in which transmissions take place by multiple-hop reflections. Knowledge of the absorption of these frequencies is also important; this can be determined if the values of electronic collisional frequencies of the E- and F-layers are known accurately, particularly at different heights in the layers themselves. If the ionic density of the F-layer could be calculated for all the intermediary points where reflections are likely to take place, not only the maximum usable frequencies but the deviations in the radiating angle, the field-strength of the reflected wave and the attenuation suffered could be theoretically determined with a high degree of accuracy. This would certainly be a great achievement.

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Radio Corporation of America,
Rca Laboratories Division,
Princeton, New Jersey, April, 1947

PROVISIONAL SUNSPOT-NUMBERS FOR APRIL TO JUNE, 1947

(Dependent alone on observation at Zurich Observatory; see notes on page 398)

Day	April	May	June
1	168	165	225
2	170	156	206
3	198	177	179
4	196	188	143
5	182	142	143
6	212	158	150
7	228	173	158
8	216	163	132
9	182	154	114
10	171	163	120
11	143	175	104
12	120	169	93
13	97	155	90
14	109	141	99
15	100	122	134
16	75	136	164
17	78	168	197
18	85	176	228
19	87	223	274
20	95	212	251
21	87	210	246
22	77	255	232
23	91	300	232
24	103	306	195
25	222	341	204
26	198	339	151
27	191	304	150
28	216	279	148
29	214	276	163
30	185	234	143
31		241	
Means........	149.9	206.5	168.9
No. days.....	30	31	30

Mean for quarter April to June, 1947: 175.4 (91 days)

Notes: Provisional sunspot-numbers are broadcast by the short-wave service of the Swiss Broadcasting Corporation according to the following schedule:

Day	GMT	Wave-lengths	For
Fourth of	(1) $07^h\ 20^m$	25.39, 25.28	Australia
each month	(2) 15 05	19.60, 16.87	Far East
	(3) 21 50	19.59	South America
	(4) 22 30	25.28	North America
	(5) 23 40	31.46, 25.28, 19.59	South America
Fifth of	(6) 01 40	31.46, 25.28, 19.59	North America
each month	(7) 03 05	31.46, 25.28, 19.59	North America

Deviations from this schedule for 1947: (*a*) Broadcast (1) on July 5 instead of July 4; (*b*) on October 3 instead of October 4. Broadcasts (3) and (5) are in Spanish and the others are in English.

Correction: Value for March 5, 1947, should read 175 instead of 165 [Terr. Mag., **52**, 174 (1947)].

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M. Waldmeier

GEOMAGNETIC DATA IN CHINA AT ZÔ-SÈ AND TSINGTAO MAGNETIC OBSERVATORIES*

Tables 1 and 2 give the geomagnetic elements so far as recorded in 1943 and 1944 and so observed with absolute instruments for three months in 1945 and 1946 and for the first five months of 1947.

Table 1—*Preliminary monthly and annual means of geomagnetic elements, all days, Zô-Sè Magnetic Observatory*

Month	D	H	Z	Month	D	H	Z
1943	° ′	γ	γ	*1944*	° ′	γ	γ
Jan.	−3 25.7	33460	33980	Jan.	−3 25.5	33480	33988
Feb.	−3 24.7	33461	33991	Feb.	−3 26.3	33485	33993
Mar.	−3 24.0	33469	33983	Mar.	−3 25.7	33469	34001
Apr.	−3 26.4	33452	33992	Apr.	−3 26.8	33498	34000
May	−3 26.3	33459	33992	May	−3 27.3	33496	34000
June	−3 25.4	33488	33989	June	−3 27.4	33515	33995
July	−3 25.9	33486	33995	July	−3 27.3	33519	34006
Aug.	−3 27.0	33460	33996	Aug.	−3 26.0	33519	34012
Sep.	−3 27.5	33451	33998	Sep.	−3 27.3	33514	34019
Oct.	−3 25.9	33456	34005	Oct.	−3 26.5	33505	34018
Nov.	−3 26.3	33470	34000	Nov.	−3 25.9	33521	34016
Dec.	−3 26.4	33476	33994	Dec.	−3 25.3	33498	34015
Means	−3 25.9	33466	33993	Means	−3 26.4	33502	34005

*As provided in Father Burgaud's letter of June 2, 1947 to the Director of the United States Coast and Geodetic Survey.

TABLE 2—*Preliminary monthly means, absolute magnetic values, Zô-Sè Magnetic Observatory*

Month	D	H	Z	Month	D	H	Z
1945	° ′	γ	γ	*1947*	° ′	γ	γ
Jan.	−3 27.5	33505	34018	Jan.	−3 28.0	33560	34094
Feb.	−3 26.1	33521	34029	Feb.	−3 27.1	33573	34108
Mar.	−3 26.0	33507	34034	Mar.	−3 26.5	33566	34120
1946				Apr.	−3 28.1	33611	34116
Oct.	−3 25.2	35546	34092	May	−3 28.7	33602	34105
Nov.	−3 29.6	35584	34102				
Dec.	−3 28.1	35581	34100				

The Tsingtao Magnetic Observatory was not operating during World War II. The variometer-building and the variometers, as well as the absolute building, were destroyed. The only instruments saved were Cook magnetometer 28, Chasselon 128, and Casella 2000. Absolute observations were resumed in September, 1946, but for the present no continuous registrations are possible.

ZÔ-SÈ MAGNETIC OBSERVATORY,
Zi-ka-wei, China, June 2, 1947

M. BURGAUD

K-INDICES, APRIL TO JUNE, 1947, AND SUDDEN COMMENCEMENTS, JANUARY TO JUNE, 1947, AT ABINGER

I enclose a list of the *K*-indices of geomagnetic activity at Abinger for April to June, 1947, in Table 1.

In view of the interest which is now attached to "Sudden-Commencement" phenomena, I append in Table 2 a list of the times at which these characteristic movements have appeared on the Abinger traces during the current year, to date [the time is "Universal Time" (UT = GMT)]. An asterisk (*) indicates that the movement, though abrupt, was not characteristically "sudden".

TABLE 1—*K-indices of geomagnetic activity and magnetic character-number (C) at Abinger Observatory, April to June, 1947*

[Range for $K = 9$ is $500\ \gamma$; scale-values of variometers in γ/mm: $D = 4.97$, $H = 4.35$, $Z = 4.35$]

Gr. day	*K*-indices for three-hour interval								*K*-sum	*C*
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24		
					April, 1947					
1	1	2	3	3	3	3	1	1	17	1
2	1	1	3	3	3	4	1	1	17	1
3	3	3	3	3	3	4	4	3	26	1
4	3	3	4	4	4	3	4	4	29	1
5	3	2	3	3	3	2	3	2	21	1
6	4	4	4	4	3	3	3	1	26	1
7	1	2	3	3	3	4	1	3	20	1
8	1	1	3	3	3	3	1	5	20	1
9	4	3	4	4	4	3	3	3	28	1
10	2	2	3	3	3	3	1	3	20	1
11	3	2	3	3	4	3	1	3	22	1
12	1	2	2	3	3	3	3	4	21	1
13	3	3	2	3	3	2	3	3	22	1
14	2	3	2	3	3	2	4	3	22	1
15	4	3	2	3	4	3	2	3	24	1
16	3	2	2	2	2	3	3	3	20	1
17	4	3	2	2	6	6	7	7	37	2
18	5	4	3	5	5	5	4	6	37	1
19	4	3	3	4	3	4	1	4	26	1
20	4	4	4	3	4	4	4	2	29	1
21	1	3	3	1	1	1	0	1	11	1
22	1	1	2	2	1	1	0	0	8	0
23	1	2	2	2	1	2	1	1	12	0
24	0	1	2	2	3	2	0	0	10	0
25	1	1	2	3	3	5	4	2	21	1
26	3	2	2	2	3	4	3	3	22	1
27	2	3	3	4	4	4	3	1	24	1
28	2	3	3	2	3	3	3	2	21	1
29	1	2	2	3	4	2	1	1	16	1
30	2	3	2	3	3	3	3	2	21	1

TABLE 1—*Continued*

Gr. day	K-indices for three-hour interval								K-sum	C
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24		
				May, 1947						
1	3	4	3	2	4	3	3	2	24	1
2	1	2	1	1	2	1	1	1	10	0
3	1	3	1	3	3	2	3	0	16	1
4	1	3	3	2	1	2	3	1	16	1
5	2	3	2	2	2	3	3	1	18	1
6	1	1	2	3	3	3	3	2	18	1
7	3	2	1	2	2	2	1	1	14	1
8	0	1	1	1	2	2	1	0	8	0
9	0	2	1	2	1	1	0	0	7	0
10	1	1	2	3	1	2	1	1	12	0
11	1	1	2	2	3	3	3	2	17	1
12	4	2	2	3	3	2	2	3	21	1
13	3	3	3	3	3	4	4	4	27	1
14	4	4	3	3	4	3	4	3	28	1
15	3	3	3	4	4	4	4	4	29	1
16	5	4	4	4	4	4	3	4	32	1
17	3	3	3	3	4	3	3	3	25	1
18	3	3	2	3	3	5	5	3	27	1
19	2	3	3	3	3	4	2	2	22	1
20	1	2	2	3	3	2	2	2	17	1
21	3	2	3	3	3	2	2	2	20	1
22	2	1	1	2	2	3	2	5	18	1
23	3	5	4	4	4	4	3	1	28	1
24	4	3	7	6	4	4	3	3	34	2
25	3	1	3	3	4	3	2	3	22	1
26	3	3	4	4	4	5	3	4	30	1
27	3	4	3	3	3	5	3	2	26	1
28	2	2	1	3	4	5	4	3	24	1
29	2	2	3	4	4	5	3	2	25	1
30	2	3	2	2	1	3	1	1	15	1
31	1	2	3	3	3	4	4	4	24	1

Table 1—*Concluded*

Gr. day	K-indices for three-hour interval								K-sum	C
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24		
				June, 1947						
1	5	5	4	3	3	2	3	1	26	1
2	0	2	1	2	2	3	2	1	13	1
3	2	4	2	3	2	3	2	1	19	1
4	1	2	3	3	2	3	3	1	18	1
5	1	3	6	4	4	5	5	5	33	1
6	5	1	2	2	1	1	3	2	17	1
7	2	3	3	4	3	3	3	5	26	1
8	4	4	3	2	3	4	3	3	26	1
9	3	4	3	3	3	4	2	3	25	1
10	3	3	2	3	3	3	3	2	22	1
11	2	2	3	2	3	3	3	1	19	1
12	2	2	3	1	3	3	3	3	20	1
13	3	2	3	3	3	5	4	5	28	1
14	5	6	5	4	4	5	6	3	38	2
15	4	4	3	3	3	3	2	2	24	1
16	2	1	1	3	3	3	3	3	19	1
17	2	4	4	4	5	6	5	3	33	2
18	2	3	3	3	3	3	3	3	23	1
19	3	3	3	3	3	4	2	3	24	1
20	2	1	3	3	2	3	3	1	18	1
21	2	2	3	4	2	3	3	3	22	1
22	2	3	3	3	3	4	4	3	25	1
23	3	2	3	2	4	4	3	1	22	1
24	2	3	2	2	3	4	3	3	22	1
25	3	4	4	3	5	4	2	3	28	1
26	2	3	3	4	3	4	3	3	25	1
27	3	2	1	1	3	2	2	1	15	1
28	1	3	2	3	3	3	3	2	20	1
29	1	2	2	3	1	2	2	2	15	1
30	3	2	3	3	3	3	3	2	22	1

TABLE 2—*Sudden-commencement phenomena at Abinger Observatory, January to June, 1947*

Month	Day and GMT (= UT)			Month	Day and GMT (= UT)		
1947	*d*	*h*	*m*	*1947*	*d*	*h*	*m*
Jan.	4	11	17.3	Apr.	3	15	01.0
	16	03	28.6		8	21	49.2
Feb.	16	02	59.0		17	12	24.8
Mar.	2	04	01*	May	22	22	13.4
	2	08	17.6		24	06	45.0
	7	05	36*	June	5	07	25.6
	15	08	41.4		13	17	49.0
	27	04	29*		17	03	01*

ROYAL OBSERVATORY,
Greenwich, London, S.E. 10, England, July 12, 1947

H. SPENCER JONES,
Astronomer Royal

CHELTENHAM *K*-INDICES FOR JANUARY TO JUNE, 1947[1]

Cheltenham *K*-indices[2] are submitted daily to the Washington Office of the United States Coast and Geodetic Survey and are currently being supplied in a weekly report to approximately the same agencies and investigators that formerly received the weekly "Report of Geomagnetic Activity" prepared by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.[3] In addition it is planned to publish quarterly tabulations of the Cheltenham *K*-indices in this JOURNAL.

K-indices are regularly scaled at all five of the standard observatories of the United States Coast and Geodetic Survey; monthly tabulations of these figures are filed in the Washington Office.

The *K*-indices for January to June 1947 are given in Table 1 as determined from the records at the Cheltenham Magnetic Observatory.

TABLE 1—*K-indices of geomagnetic activity at Cheltenham Magnetic Observatory, January to June, 1947*

[Range for $K = 9$ is 500 γ; scale-values of variometers in γ/mm: $D = 5.34$, $H = 2.65$, $Z = 4.1$]

Gr. day	*K*-indices for three-hour interval								*K*-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
	January, 1947								
1	1	1	1	3	2	1	0	0	8
2	0	0	3	3	2	3	2	2	15
3	1	3	2	1	2	2	3	3	17
4	3	1	1	4	4	4	3	3	23
5	3	3	3	4	3	2	4	2	24
6	4	5	3	4	4	2	1	2	25
7	3	3	2	1	2	1	1	1	14
8	2	2	3	3	0	1	1	0	12
9	0	0	1	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	1	0	0	0	1	0	2	0	4
15	0	1	0	2	2	1	2	1	9
16	1	5	3	2	4	4	4	3	26
17	2	2	2	4	3	1	2	2	18
18	2	0	3	3	1	1	2	2	14
19	2	1	2	2	1	1	1	2	12
20	1	1	0	0	1	1	2	1	7
21	2	1	1	0	1	0	1	0	6
22	1	0	1	1	1	1	1	2	8
23	1	2	0	0	2	1	1	2	9
24	1	1	4	4	2	2	3	3	20
25	4	5	5	6	5	4	3	4	36
26	4	4	3	3	4	3	3	2	26
27	2	4	1	1	3	3	3	2	19
28	4	1	2	1	1	1	2	2	14
29	0	4	2	3	3	2	1	0	15
30	1	0	1	2	1	0	0	3	8
31	2	3	1	1	0	0	1	1	9

[1]Published by permission of the Director, United States Coast and Geodetic Survey.

[2]*K*-indices are described by J. Bartels, N. H. Heck, and H. F. Johnston in Terr. Mag., **44**, 411-454 (1939).

[3]W. E. Scott, Terr. Mag., **52**, 15-24 (1947).

TABLE 1—*Continued*

Gr. day	K-indices for three-hour interval								K-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
				February, 1947					
1	1	2	3	1	2	0	2	1	12
2	0	0	0	0	0	1	1	1	3
3	1	0	3	3	1	2	3	1	14
4	3	3	3	3	2	1	2	0	17
5	1	0	0	1	2	1	2	1	8
6	2	2	4	2	2	1	1	2	16
7	0	0	2	2	3	2	2	0	11
8	2	2	4	5	4	3	2	3	25
9	4	5	3	3	1	3	4	3	26
10	3	2	2	3	3	3	1	0	17
11	1	1	0	0	1	1	2	3	9
12	1	1	0	1	1	2	0	2	8
13	1	2	1	0	2	0	1	0	7
14	0	0	2	0	0	1	2	2	7
15	0	1	0	1	1	1	0	0	4
16	0	3	3	6	5	4	4	3	28
17	6	6	4	4	3	2	3	0	28
18	2	3	2	2	3	1	2	3	18
19	3	1	3	1	4	4	3	3	22
20	4	4	0	0	1	1	0	0	10
21	0	0	0	0	1	0	0	1	2
22	0	0	0	0	0	0	1	1	2
23	0	0	0	0	0	0	0	0	0
24	2	1	0	2	3	1	1	2	12
25	2	2	2	3	3	1	2	3	18
26	3	4	3	2	2	2	1	1	18
27	2	3	0	0	1	0	0	0	6
28	1	1	3	1	1	1	2	2	12

TABLE 1—*Continued*

Gr. day	*K*-indices for three-hour interval								*K*-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
				March, 1947					
1	2	2	2	1	1	1	1	2	12
2	2	4	6	6	5	5	6	5	39
3	7	5	6	6	6	4	8	7	49
4	7	6	6	6	3	2	4	1	35
5	4	1	4	2	2	1	1	1	16
6	1	1	1	2	2	1	1	1	10
7	1	2	3	3	5	3	4	3	24
8	2	3	5	5	6	5	5	6	37
9	6	5	5	5	5	2	3	2	33
10	2	2	1	1	2	1	1	2	12
11	0	0	3	3	2	1	0	2	11
12	2	3	2	3	4	4	2	3	23
13	3	2	3	3	4	2	4	2	23
14	2	3	4	3	4	4	3	3	26
15	2	3	6	7	6	5	5	3	37
16	2	2	2	1	2	2	3	3	17
17	5	3	3	3	4	1	2	2	23
18	2	3	0	2	3	3	3	2	18
19	3	2	2	0	2	2	2	2	15
20	3	4	3	1	1	1	2	1	16
21	1	2	2	1	2	2	1	3	14
22	2	4	3	4	3	2	2	2	22
23	2	3	3	4	5	6	3	4	30
24	4	5	4	2	2	3	2	3	25
25	2	3	4	3	0	1	2	4	19
26	4	4	3	4	3	2	2	3	25
27	3	4	4	4	2	3	3	4	27
28	6	6	6	6	4	4	2	3	37
29	3	2	1	1	2	2	3	4	18
30	5	4	3	4	3	3	4	3	29
31	3	4	4	4	3	3	1	1	23

TABLE 1—*Continued*

Gr. day	*K*-indices for three-hour interval								*K*-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
				April, 1947					
1	2	1	3	3	2	1	1	2	15
2	1	2	2	2	3	2	1	1	14
3	2	3	1	0	1	3	4	3	17
4	2	3	3	4	3	3	3	4	25
5	3	1	0	1	1	2	2	2	12
6	4	3	3	4	2	2	1	3	22
7	1	2	0	1	2	2	1	2	11
8	1	1	1	3	2	1	1	6	16
9	5	4	6	5	4	3	3	3	33
10	3	2	4	2	2	1	1	3	18
11	3	3	2	3	2	2	2	3	20
12	1	2	3	3	2	2	3	3	19
13	2	2	2	2	2	1	2	1	14
14	1	3	3	2	2	1	2	2	16
15	4	4	2	3	2	3	3	3	24
16	3	2	3	2	3	3	2	2	20
17	3	5	1	2	6	6	8	9	40
18	5	3	3	5	4	3	4	4	31
19	5	3	4	4	3	3	2	4	28
20	3	5	5	4	3	2	4	3	29
21	2	4	4	1	0	0	1	2	14
22	0	1	0	1	0	0	0	0	2
23	1	2	0	0	1	2	2	1	9
24	0	1	1	0	0	0	0	0	2
25	1	0	0	1	1	4	2	2	11
26	2	1	2	2	1	3	5	5	21
27	2	2	3	3	3	2	3	2	20
28	1	4	2	1	3	2	3	3	19
29	1	2	3	4	3	2	2	2	19
30	2	4	2	4	2	2	3	3	22

TABLE 1—*Continued*

Gr. day	K-indices for three-hour interval								K-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
				May, 1947					
1	3	4	3	3	4	2	1	1	21
2	2	1	0	0	1	0	1	2	7
3	1	2	1	1	2	0	1	1	9
4	1	1	2	2	0	1	1	1	9
5	2	3	2	1	0	2	3	2	15
6	0	1	1	0	1	1	1	2	7
7	4	1	0	1	1	1	0	0	[illegible]
8	0	0	1	1	0	0	0	1	3
9	1	1	0	0	0	1	0	0	3
10	0	1	2	1	1	1	2	1	9
11	2	1	2	2	2	1	2	3	15
12	4	3	1	3	2	1	2	4	20
13	3	2	3	2	2	2	3	5	22
14	4	4	3	4	3	3	3	3	27
15	4	4	4	3	3	3	4	4	29
16	4	6	5	4	4	3	3	4	33
17	2	3	3	2	3	3	3	3	22
18	2	3	3	2	2	3	3	3	21
19	3	3	3	3	1	2	1	1	17
20	2	2	3	2	1	1	2	3	16
21	2	1	4	1	1	1	3	3	16
22	2	1	0	1	0	0	2	6	12
23	4	5	4	3	2	3	3	3	27
24	4	3	7	7	4	3	3	4	35
25	3	2	3	3	2	2	2	3	20
26	2	3	4	3	3	3	4	5	27
27	3	3	3	2	3	3	3	3	23
28	2	1	1	2	5	4	4	4	23
29	2	3	3	4	3	3	2	1	21
30	2	1	1	1	0	2	0	1	8
31	1	2	2	3	2	3	4	4	21

TABLE 1—*Concluded*

Gr. day	*K*-indices for three-hour interval								*K*-sum
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
				June, 1947					
1	4	5	5	3	2	1	2	2	24
2	1	1	1	2	1	2	1	1	10
3	2	4	2	2	2	2	2	1	17
4	1	1	2	2	2	2	2	1	13
5	2	3	5	4	4	3	4	5	30
6	5	2	1	0	0	1	2	2	13
7	2	3	3	2	3	3	4	5	25
8	3	4	3	3	3	3	3	3	25
9	3	4	4	3	2	3	3	3	25
10	2	3	2	2	1	1	2	3	16
11	2	2	3	2	2	3	2	3	19
12	2	2	3	1	2	1	3	3	17
13	3	2	3	2	2	4	5	4	25
14	6	6	5	5	4	3	6	4	39
15	4	3	3	4	3	4	3	3	27
16	3	2	2	1	2	2	3	3	18
17	3	6	4	4	3	5	5	4	34
18	3	4	3	3	1	1	3	3	21
19	2	5	1	2	2	2	3	3	20
20	2	3	3	2	2	2	2	2	18
21	2	2	2	2	1	2	2	4	17
22	3	3	2	2	2	3	3	5	23
23	4	3	3	3	3	3	3	2	24
24	3	2	2	3	2	3	3	3	21
25	3	4	4	4	3	2	3	4	27
26	2	3	4	3	2	3	3	4	24
27	2	1	3	1	2	2	2	2	15
28	2	3	2	3	2	1	2	2	17
29	1	3	2	1	1	2	1	2	13
30	3	2	4	4	2	2	2	2	21

CHELTENHAM MAGNETIC OBSERVATORY,
Cheltenham, Maryland, July 15, 1947

WILLIAM E. WILES,
Observer-in-Charge

RECENT GEOMAGNETIC DATA FROM OBSERVATORIES AND STATIONS IN JAPAN

The geomagnetic data listed in Tables 1 and 2 are taken from the "Preliminary report of magnetic weather data from magnetic observatories and weather stations" supplied to the Commanding Officer, Headquarters 43d Weather Wing, in Tokyo.

TABLE 1—*Geomagnetic data as determined at stations in Japan, 1939-41*

Month	Year			Year		
	1939	1940	1941	1939	1940	1941
	° ′	° ′	° ′	° ′	° ′	° ′
	Otomari* (46° 38′.8 N, 42° 14′.5 E)			Zinsen (37° 28′.5 N, 126° 37′.5 E)		
Jan.	−8 55.8	−9 00.5	−9 02.3	−6 11.7	−6 15.4	−6 15.4
Feb.	−8 57.0	−9 00.2	−9 03.1	−6 12.6	−6 14.3	−6 16.3
Mar.	−8 58.2	−9 02.4	−9 03.3	−6 12.8	−6 14.4	−6 12.2
Apr.	−8 59.8	−9 00.7	−9 04.6	−6 12.4	−6 14.4	−6 12.9
May	−8 58.5	−8 59.2	−9 02.4	−6 13.0	−6 14.6	−6 15.5
June	−8 57.8	−9 01.0	−9 01.8	−6 12.3	−6 14.0	−6 17.1
July	−8 57.9	−9 00.5	−9 05.3	−6 13.0	−6 14.9	−6 18.0
Aug.	−8 58.4	−9 01.9	−9 04.7	−6 12.9	−6 14.2	−6 19.9
Sep.	−8 58.2	−9 00.8	−9 01.9	−6 12.7	−6 14.9	−6 19.5
Oct.	−9 00.7	−9 00.8	−9 03.9	−6 13.7	−6 14.4	−6 18.6
Nov.	−8 59.4	−9 01.1	−9 04.6	−6 13.4	−6 14.6	−6 18.9
Dec.	−9 00.6	−9 00.2	−9 04.5	−6 14.6	−6 15.7	−6 19.4
Means	−8 58.5	−9 00.8	−9 03.6	−6 12.9	−6 14.6	−6 17.0
	Taihoku (25° 02′.3 N, 121° 30′.8 E)			Marcus (Minamitori, Shima)** (24°.3 N, 154°.0 E)		
Jan.	−2 10.0	−2 09.9	... .	... .	... .	... .
Feb.	−2 10.2	−2 09.3	... .	... .	... .	... .
Mar.	−2 09.8	−2 09.8	... .	... .	... .	... .
Apr.	−2 10.0	−2 09.8	... .	... .	... .	... .
May	−2 09.9	−2 09.5	... .	... .	... .	+0 15.1
June	−2 09.8	−2 09.5	... .	... .	... .	+0 14.5
July	−2 09.9	−2 09.3	... .	... .	... .	+0 15.4
Aug.	−2 09.6	−2 09.4	... .	... .	... .	+0 15.2
Sep.	−2 09.6	−2 09.3	... .	... .	... .	+0 15.0
Oct.	−2 09.4	−2 08.9	... .	... .	... .	+0 14.0
Nov.	−2 09.8	−2 09.2	... .	... .	... .	+0 15.6
Dec.	−2 09.8	−2 08.5	... .	... .	... .	+0 18.1
Means	−2 09.8	−2 09.4	... .	... .	... .	... .

*Values of H and Z not yet received; data for 1942 to 1945 were destroyed by air-raid fire. **Absolute observations only of D for eight months from May, 1941.

TABLE 1—*Concluded*

Month	Year 1939	Year 1940	Year 1941	Year 1939	Year 1940	Year 1941
	° ′	° ′	° ′	° ′	° ′	° ′
	Palau* (7° 20′.0 N, 134° 29′.0 E)			Yaluit (5° 54′.9 N, 169° 39′.1 E)		
Jan.	+2 08.6	+2 07.2	+2 05.3	+7 50.9	+7 48.9	+7 52.5
Feb.	+2 08.4	+2 07.2	+2 05.9	+7 50.8	+7 50.7	+7 53.9
Mar.	+2 07.1	+2 06.5	+2 05.4	+7 50.2	+7 51.8	+7 54.1
Apr.	+2 08.1	+2 07.0	+2 05.1	+7 49.8	+7 51.0	+7 53.3
May	+2 07.5	+2 05.9	+2 06.5	+7 50.6	+7 52.5	+7 51.9
June	+2 08.4	+2 07.1	+2 05.1	+7 48.8	+7 53.3	+7 53.4
July	+2 08.3	+2 06.4	+2 05.5	+7 51.1	+7 51.9	+7 55.8
Aug.	+2 07.3	+2 06.4	+2 06.1	+7 50.3	+7 52.4	+7 53.7
Sep.	+2 06.6	+2 03.5	+2 12.1	+7 49.5	+7 52.4	+7 55.3
Oct.	+2 07.2	+2 06.4	+2 07.6	+7 48.7	+7 53.0	+7 54.7
Nov.	+2 05.6	+2 06.3	+2 10.5	+7 49.2	+7 52.9	.. ....
Dec.	+2 06.5	+2 04.0	+2 10.6	+7 48.9	+7 52.5	+7 55.7
Means	+2 07.5	+2 06.1	+2 07.2	+7 49.9	+7 51.9	+7 54.0

TABLE 2—*Geomagnetic elements, Kakioka Observatory, 1913-1946*
[Latitude, 36° 13′.8 north; longitude, 140° 11′.4 east]

Year	*D*	*H*	*Z*	Year	*D*	*H*	*Z*
	° ′	γ	γ		° ′	γ	γ
1913	−5 10.13	29749.3	34850.8	1940	−6 00.30	29747.3	34869.1
1914	−5 12.87	29783.4	34867.6	1941	−6 01.42	29769.8	34884.5
1915	−5 15.59	29752.4	34862.6	1942	−6 02.34	29816.5	34895.8
1916	−5 17.60	29742.4	34859.4	1943	−6 03.68	29835.7	34913.4
1924*	−5 31.60	29707.5	34774.0	1944	−6 05.16	29870.9	34942.8
1925	−5 34.37	29716.0	34748.6	1945	−6 07.75	29885.9	34960.4
1926	−5 36.60	29694.0	34721.2	1946	−6 10.68	29886.3	34984.9
1927	−5 39.62	29701.6	34727.2	Monthly values, year 1946			
1928	−5 40.51	29707.3	34721.3	Jan.	−6 09.10	29889.7	34958.2
1929	−5 41.88	29703.8	34698.4	Feb.	−6 09.90	29879.5	34943.1
1930	−5 42.43	29713.4	34746.5	Mar.	−6 10.06	29879.0	34958.6
1931	−5 42.83	29733.6	34765.1	Apr.	−6 10.72	29870.9	34972.3
1932	−5 44.15	29721.9	34777.6	May	−6 10.60	29886.8	34979.5
1933	−5 45.62	29724.2	34786.3	June	−6 10.65	29897.4	34990.8
1934	−5 47.15	29721.2	34788.2	July	−6 11.15	29883.7	34994.0
1935	−5 49.44	29719.1	34822.7	Aug.	−6 10.95	29897.7	35011.1
1936	−5 51.74	29712.7	34822.7	Sep.	−6 11.54	29868.4	35025.8
1937	−5 54.23	29717.0	34843.3	Oct.	−6 11.20	29884.9	34991.0
1938	−5 56.40	29727.1	34853.8	Nov.	−6 11.24	29888.5	34993.5
1939	−5 57.92	29736.5	34850.3	Dec.	−6 11.06	29908.5	35000.7

*Data for 1917 to 1923 were lost in the fire at Tokyo, following the Kanto Earthquake on September 1, 1923.

Besides the pertinent footnotes to Tables 1 and 2, the following notes are made:

Data for the Toyohara Observatory are in preparation. No magnetic observations were made at Shimoda before and since 1939. Registrations of the three elements were made at Aso from its start but no control by absolute observations was made. An absolute observatory-room was constructed at Miyako but no observations were made. In August, 1946, a new magnetic observatory was constructed at Ikutora (latitude 43°.2 north, longitude 141°.8 east) in Hokkaido, but no observations have been made as yet. Since November, 1946, D has been determined by the Hydrographic Department at Katsuura (latitude 33° 37′.8 north, longitude 135 56′.9 east) in Chiba Prefecture.

The series of annual values, as in Table 2, at Kakioka vary somewhat from those previously published.

The data for magnetic field-stations are in preparation, as also those for Japan and Japanese occupied areas. An isogonic map covering Asia and regions of Pacific and South Pacific by Dr. T. Nagata of the Geophysical Institute of the Tokyo Imperial University has been submitted in manuscript form.

Central Meteorological Observatory, K. Wadachi,
Otemachi, Chiyoda-ku, Tokyo, Japan, June 12, 1947 *Director*

NOTES

(See also pages 341, 355, 367, and 374)

O. H. Gish and Dr. *G. R. Wait* of DTM CIW left early in August, 1947, to conduct observations on thunderstorms for the Army.

Dr. *Ellis A. Johnson* and *O. W. Torreson* of DTM CIW will make an expedition in a specially equipped truck beginning sometime during September, 1947, for the purpose of collecting varves in New England.

Paul F. Michelsen joined the staff of DTM CIW as Laboratory Assistant, April 21, 1947.

W. Dudley Parkinson returned from the Huancayo Magnetic Observatory where he has been conducting some special atmospheric-electric observations in September, 1947, to accept a Carnegie Institution Fellowship for graduate study.

Dr. *Howard Tatel* joined the staff of DTM CIW September 1, 1947, for geophysical research of the atmosphere and the crust of the Earth.

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

APRIL TO JUNE, 1947

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h $01^m.3$ W. of Gr.)

April 8-9—A moderately disturbed period began abruptly at 21^h 51^m GMT, April 8. For the first 9.5 hours there was but little activity; however, at 07^h 20^m, April 9, both H and Z began to decrease. By 08^h 17^m H had decreased about 735 gammas. Both elements remained abnormally low until about 12^h, April 9, when they gradually recovered to their normal values. It may be said that the disturbance ended at about 12^h, April 9, but minor disturbances were recorded for several days following. K-indices of 8 and 7 were recorded between 06^h and 12^h, April 9.

April 17-21—A rather long disturbance began sharply at 12^h 26^m GMT, April 17. Activity in general, was that of short-period, large-amplitude oscillations until 00^h, April 18, at which time this activity was replaced by short-period, low-amplitude oscillations. At about 10^h, April 18, the most disturbed portion of the storm was recorded and this rather severe activity continued until about 17^h, April 18. For several days magnetic conditions continued to be moderately disturbed with a marked increase in activity during the dark hours of the period. At the beginning of April 21 there appeared lulls which seemed to indicate that the disturbance was dying out and at 10^h, April 21, the storm may be said to have had its ending. The most disturbed portion of the storm caused H to decrease about 760 gammas and then recover almost instantly. K-indices 7, 8, and 7 were recorded between 09^h and 18^h, April 18.

May 13-19—A prolonged period of moderately disturbed magnetic conditions began gradually at about 21^h GMT, May 13. The first activity was that of the formation of large bays but this sort of activity was replaced by short-period, low-amplitude oscillations at about 12^h, May 14, which continued until about 21^h, May 17. The disturbance finally died out at about 09^h, May 19. K-indices of 6 were recorded for the periods: 09^h to 12^h, May 14, 06^h-09^h, and 12^h-15^h, May 16.

May 22-25—A moderate storm began rather abruptly at 22^h 45^m GMT, May 22. Although there was no violent activity during this disturbance there were two flare-ups which resulted in the production of K-indices of 7. These two periods were 06^h-09^h ,May 23, and 06^h-12^h, May 24. The disturbance may be said to have ended at 13^h, May 25; however, the traces for the remainder of the month showed signs of lesser disturbances with the exception of the period between 00^h, May 30, and 03^h, May 31, when conditions were undisturbed.

June 13-14—A minor storm began abruptly at 17^h 49^m GMT, June 13. For the first 3.5 hours there was little activity; however, at about 21^h 30^m, June 13, all elements began to show signs of increased activity and this condition existed until about 11^h, June 14. Oscillations of short period and low amplitude followed for the next ten hours and at 21^h, June 14, the storm died out. Four *K*-indices of 7 were recorded for the period 00^h to 12^h, June 14.

June 25-27—Magnetic conditions were moderately disturbed between 01^h GMT, June 25, and about 04^h, June 27. In general, the activity during this disturbance was composed of short-period, low-amplitude oscillations superposed on large bays. A *K*-index of 6 was recorded between 09^h and 12^h, June 25 and a 7 was recorded between 09^h and 12^h, June 26.

Joel B. Campbell, *Observer-in-Charge*

Cheltenham Magnetic Observatory

April to June, 1947

(*Latitude 38° 44'.0 N., longitude 76° 50'.5 or 5^h $07^m.4$ W. of Gr.*)

April 8—A minor disturbance began with a sudden commencement in all three elements at 21^h 49^m GMT, April 8. *H* suddenly decreased 50 gammas and then increased 148 gammas, both changes taking place in about two minutes. Irregular oscillations of moderate amplitude appeared in all three elements. The disturbance subsided by 14^h. Two *K*-indices of 6 and two of 5 were recorded.

April 17-20—A severe storm, exhibiting an unusual increase in both *H* and *Z*, began with a sudden commencement at 12^h 25^m GMT, April 17. After seven hours of long-period motion, both *H* and *Z* began to increase rapidly at 19^h, April 17. *Z* reached a maximum value at about 21^h 12^m, having increased 500 gammas from a minimum during the 16th hour. *Z* began to decrease rapidly between 22^h and 23^h, and within three hours attained normal proportions. Peaks in *H* occurred at 20^h 44^m and 20^h 56^m, and maximum *H* at 22^h 09^m. Minimum *H* of 18,106 gammas occurred at 15^h 38^m, a range of 539 gammas being scaled. During the intense part of the storm from 19^h, April 17, to 02^h, April 18, *D* exhibited rapid, irregular oscillations and ranged in value by 39'. Although the main activity was short-lived, all three elements remained disturbed for several days with a minor outbreak of irregular oscillations taking place between 05^h and 10^h, April 20. Short-period oscillations in all three traces were particularly evident from 10^h to about 17^h, April 18. At other times long-period motion of moderate amplitude prevailed. Normal conditions were resumed at

roughly 13^h, April 20. K-indices for the last four intervals of April 17 were 6, 6, 8, and 9, respectively.

May 13-16—A prolonged period of comparatively minor disturbance began at about 18^h GMT, May 13, with a slight disturbance in H and ended, roughly, at midnight, May 16. Long-period motion of generally small amplitude predominated. Some short-period motion in H took place especially in the last few hours of May 14. The greatest disturbance occurred between 03^h and 09^h, May 16, during which intervals K-indices of 6 and 5 were recorded and D showed a disturbance range of 27′.

May 22-24—A magnetic storm began with a pronounced sudden commencement in H at $22^h\ 44^m$ GMT, May 22, with minor beginnings in D and Z, and subsided by midnight, May 24. At the commencement H suddenly decreased 18 gammas and then increased 122 gammas in three minutes. Although the storm consisted largely of minor irregular and long-period disturbances of usually rather small amplitude, an intense and well-defined bay occurred in all three elements between 07^h and 10^h, May 24. During this interval H decreased 223 gammas reaching a minimum of 18,074 gammas at $09^h\ 01^m$ and Z decreased 250 gammas between $06^h\ 47^m$ and $08^h\ 52^m$. D increased westerly until $08^h\ 30^m$ when a westerly extreme of 7° 43′ was reached. D then decreased 53′ in the ensuing forty minutes. During the bay two K-indices of 7 were scaled for the K-intervals between 06^h and 12^h.

June 5-6—A minor magnetic storm lasting less than a day began with a sudden commencement in all three elements at $07^h\ 26^m$ GMT, June 5. At the commencemen H suddenly increased 82 gammas. The ensuing perturbations for all elements were irregular and of moderate and small amplitudes. The disturbance subsided by 02^h, June 6. Three K-indices of 5 were recorded.

June 13-14—A moderate magnetic storm began with a sudden commencement in all three elements at $17^h\ 49^m$ GMT, June 13. The H-trace exhibited irregular oscillations of generally moderate amplitude until $19^h\ 31^m$, June 14, at which time pronounced rapid oscillations of moderate amplitude occurred for two hours. The Z-trace was most disturbed between 00^h and 05^h, June 14, between which times a range of 221 gammas was scaled. The D-trace exhibited long-period motion of rather large amplitude until $17^h\ 26^m$, June 14, after which short-period motion of small amplitude prevailed for about four hours. Major disturbance for all elements had subsided by midnight, June 14. Three K-indices of 6, two of 5, and a K-sum of 39 occurred on the Greenwich day of June 14.

June 17—A minor storm began with a sudden commencement in D and H at $03^h\ 01^m$ GMT, June 17, and continued until about midnight. For the first nine hours irregular motion of moderate amplitude occurred in all three elements. This was followed by about six hours of rapid pulsations

of rather small amplitude in both H and D. From 18^h to 24^h, irregular oscillations of moderate amplitude appeared. The K sum for the day was 34 with one K-index of 6 and two of 5 being recorded.

William E. Wiles, *Observer-in-Charge*

Tucson Magnetic Observatory

April to June, 1947

(Latitude 32° 14'.8 N., longitude 110° 50'.1 or 7^h $23^m.3$ W. of Gr.)

April 8-9—A storm of only about eighteen hours' duration began suddenly at 21^h 50^m GMT, April 8, with an increase of about 55 gammas in H and corresponding changes in D and Z. Except for the magnitude of the initial displacement of the traces, the storm-intensity was quite moderate, with no unusual characteristics. Ranges: H, 131 gammas; D, 13'.

April 17-20—At 12^h 25^m GMT, April 17, a momentary small decrease and then a rapid increase of 65 gammas in H constituted the sudden commencement of a moderately severe storm. The commencement as registered on the D-trace was an increase of 1'.5 in eastward D and then a decrease of 4'.5. Small, irregular oscillations superimposed on large changes of all elements occurred during the first twelve hours. Minimum H was attained at 20^h 58^m, April 17. The large swings died out at 00^h, April 18. Activity of small, irregular character, gradually decreasing, continued for more than two days. At 05^h April 20, a period of moderate disturbance began; it lasted six hours. The storm ended about 12^h, April 20. Ranges: H, 312 gammas; D, 37'.5; Z, 57 gammas.

May 13-18—Mild storm-conditions became evident during the first half of the Greenwich day May 13. Moderate magnetic roughness without special character continued for several days, ending probably on May 18.

May 22-25—A sudden drop of 8 gammas, followed immediately by a rapid increase of 70 gammas in H, beginning at 22^h 43^m GMT, May 22, was the sudden commencement of a moderate storm. Ranges were small and irregular during the first thirty hours. From 06^h to 12^h, May 24, there were several large swings in D and H. Following this there was a 24-hour period of small, irregular changes before the end of the storm about the middle of the Greenwich day, May 25. Ranges: H, 190 gammas; D, 26'.

June 5-6—A sudden commencement, consisting of a rapid 78-gamma increase in H with corresponding disturbances in D and Z, occurred at 07^h 26^m GMT, June 5. The storm was of short duration, lasting only eighteen hours. Its outstanding characteristic seemed to be a continued higher-than-normal H until about three hours before the storm ending.

which came quite suddenly at 02^h, June 6. Ranges: H, 190 gammas; D, 21′.

June 13-15—At 17^h 48^m GMT, June 13, an increase in H and a decrease in eastward D marked the beginning of a moderate storm. The commencement, however, was unusual in that the increase in H was slower and smaller than would be expected for a storm of this magnitude. The beginning was followed by several hours of relative quiet. At 00^h, June 14, a period of moderately large, slow changes in D and H commenced and lasted for about ten hours. Between $19^h.5$ and 20^h, June 14, there appeared some rapid oscillations in H with a total range of 93 gammas; the corresponding disturbance on D and Z was small. Most of the activity had died out by 12^h, June 15. Ranges: H, 163 gammas; D, 19′.

June 17-18—A mild storm began about 03^h GMT, June 17, and continued for approximately twenty-four hours. Its principal characteristic seemed to be an interval of about seven hours, between 13^h and 20^h, of rapid, short-period, irregular oscillations of amplitudes up to 18 gammas in H.

J. H. Nelson, *Observer-in-Charge*

Zô-Sè Observatory

April to June, 1947

(Latitude 31° 05′.8 N., longitude 121° 11′.2 or 8^h 04^m 45^s E. of Gr.)

April 3—A minor disturbance began with small abrupt beginning of 15 gammas at 23^h 02^m GMT. A small solar effect was noted a few hours before.

April 8—A sudden rise of 29 gammas in H at 21^h 49^m GMT was followed by a restricted disturbance lasting for nearly one day.

April 17-20—A very characterized storm began at 12^h 25^m GMT, April 17, with an abrupt commencement of 68 gammas in two minutes and a sudden increase of the Z of 10 gammas. Range was rather large amounting to 330 gammas—maximum at 12^h 28^m, acute and deep minimum at about 21^h 35^m. Disturbance was over at about 16^h, April 19. Recovery of H towards normal values was slow on April 20. A short period of storm was again noticed from 17^h to 21^h, April 20.

April 25—Two small and not very sharp rises were noted at 15^h 15^m and 16^h 25^m, GMT, April 25, followed by disturbed conditions during two days.

May 1—A possible world-wide feature was noticed in H at 03^h 03^m GMT in a decrease of 25 gammas in ten minutes followed by calm and slow recovery. Magnetic needle was pushed westward by 2′ and the vertical force increased by 8 gammas.

May 15—A small rise (not a sharp beginning) of 14 gammas in seven minutes took place at $00^h\ 17^m$ GMT preceding disturbed curves during two days.

May 20-21—A moderate storm with two sudden commencements was recorded, namely, a preliminary one of 31 gammas at $22^h\ 44^m$ GMT, May 20, followed by a second four hours later at $02^h\ 42^m$. Rather calm conditions prevailed in the interval. The storm appeared to be nearly over when a fresh and rather large disturbance began with a very sharp impulse at $01^h\ 02^m$, May 24; *H* decreased from 07^h to 09^h. Range of the new storm amounted to 242 gammas in *H*.

June 5-6—A sudden and very sharp rise of 60 gammas in *H* opened a new minor storm in two minutes; range was not large (127 gammas). The minimum occurred one hour later at about $08^h\ 35^m$ GMT. Small fluctuations took place with a slow recovery of *H* when at $20^h\ 42^m$ there was a sudden drop in *H* of 76 gammas; a rather extended minimum occurred at about 01^h, June 6.

June 13-14—Sudden-commencement of 27 gammas at $17^h\ 47^m$ GMT, June 13, was ahead of an ordinary storm. Principal features were: Extended maximum of three hours; slow drop in *H* and short but sharp variations from 02^h to 09^h, June 14.

June 17—A new period of moderate activity was noticed between 03^h GMT and 18^h, June 17, with a range of 110 gammas. Maximum was at about $03^h\ 30^m$ and minimum six hours later.

Notes on radio fade-outs reported in the Chinese Government Administration and solar effects at Zô-Sè. The letters *L*, *SF*, *C*, and *H* indicate radio circuits from Shanghai to London, San Francisco, Colombo, and Hongkong, respectively.

Date	Times fade-outs	Radio circuits	Time solar effect	Remarks
1947	*h m h m*		*h m h m*	
Jan. 14	06 25-06 55	*SF, H, C*	06 17-07 00	Important
15	01 15-01 25	*SF, C*	00 04-01 19	Well marked
Feb. 13	23 15-23 30	*SF*	23 08-23 29	Small
	22 10-24 30	*C*	. . . .	. . . .
17	01 00-02 20	*SF*	. . . .	. . . .
	01 20-02 30	*C*	. . . .	No pulse
18	05 30-05 45	*SF*	05 25-05 55	Clear, ordinary
	05 30-06 30	*C*	. . . .	. . . .
	05 30-05 40	*H*	. . . .	. . . .
19	02 40-03 45	*SF, C, H*	. . . .	No pulse
23	. . . .	. . . .	01 50-02 05	Small, clear
27	01 10-01 40	*SF*	01 13	Small mark
	. . . .	. . . .	07 10-07 16	Small, sharp
Mar. 6	03 25-03 40	*SF, C, H*	03 18-03 30	Small
7	07 10-08 15	*SF*	. . . .	. . . .

Date	Times fade-outs	Radio Circuits	Time solar effect	Remarks
1947	*h m h m*		*h m h m*	
Mar. 7	06 15-07 15	*L*	....	....
	06 15-07 30	*C*	....	No pulse
	06 20-07 15	*H*	....	....
10	06 00-06 14	*L*	06 00-06 16	Small
	06 00-06 10	*C*	....	....
13	06 25-06 45	*L*	06 20-06 45	Ordinary
	06 25-06 42	*C*	....	....
	06 25-06 40	*H*	....	....
14	02 55-03 40	*SF, H*	....	No pulse
	02 55-03 50	*C*	....	....
	07 10-07 25	*L*	....	No pulse
	07 10-07 20	*C*	....	....
16	07 25-07 40	*L, C, H*	07 28-07 50	Pronounced
	07 27-07 40	*SF*	....	....
29	04 43-05 10	*SF*	04 37-05 25	Important
	04 43-05 15	*C*	....	....
	04 43-05 25	*H*	....	....
30	23 00-24 00	*SF*	....	....
	23 00- ?	*L, ZMQ*	....	No pulse
	23 00-23 45	*H*	....	....
31	01 20-01 35	*SF*	....	....
	01 25-01 50	*C*	....	No pulse
	01 25-01 45	*H*	....	....

M. Burgaud, *Director*

Alibag Magnetic Observatory

April to June, 1947

(*Latitude 18° 38′.3 N., longitude 72° 52′.3 or 4^h $51^m.5$ E. of Gr.*)

April 17-18—A sudden-commencement storm of great intensity with an increase of 62 gammas in *H*, a decrease of 20 gammas in *Z*, and an increase in westerly declination of 1′.5 (all in about three minutes) began at 12^h 24^m GMT, April 17. After a period of moderate intensity lasting for about seven hours, *H* fell rapidly at 19^h 38^m until 21^h 35^m when the minimum was reached. Thereafter *H* increased rapidly and began to fluctuate. The storm ended at about 22^h 30^m, April 18, recording two *K*-indices of 8 for the successive intervals 18^h-24^h, April 17, and four K-indices of 6. Ranges: *D*, 9′.8; *H*, 429 gammas; *Z*, 103 gammas.

May 22-24—A storm of moderate intensity commenced suddenly at 22^h 43^m GMT, May 22, and continued until about 18^h 30^m, May 22, giving only one *K*-index of 5, and later merged into another storm of moderate intensity which began suddenly at 02^h 12^m, May 24, becoming intense

during the period $06^h\ 45^m$ to 10^h, May 24. The disturbance ended at about 15^h, giving only one *K*-index of 7. Ranges: *D*, 4′.9; *H*, 225 gammas; *Z*, 51 gammas.

June 5—A moderate disturbance began at $07^h\ 26^m$ GMT, June 5, with a sudden rise of 58 gammas in *H*, a decrease of 19 gammas in *Z*, and an increase of 1′.2 in westerly declination. The disturbance ended at about 00^h, June 6, recording some fluctuations after about two hours of commencement. One *K*-index of 6 and one of 5 were recorded during the disturbance. Ranges: *D*, 4′.9; *H* 198 gammas; *Z*, 51 gammas.

June 13-14—A moderate disturbance began with a sudden commencement at $17^h\ 50^m$ GMT, June 13, with an increase of 29 gammas in *H*, a decrease of 5 gammas in *Z*, and an increase of 0′.8 in westerly declination. It was followed by some sharp rise and fall in *H* and a corresponding fall and rise in the *Z*- and *D*-records. Ranges: *D*, 9′.3; *H*, 143 gammas; *Z*, 86 gammas.

M. P. Rao, *Assistant.*

Huancayo Magnetic Observatory

April to June, 1947

(Latitude 12° 02′.7 S., longitude 76° 20′.4 or $5^h\ 01^m.4$ W. of Gr.)

April 8—There was a sudden increase in *H* of 115 gammas in three minutes beginning at $21^h\ 50^m$ GMT, April 8, which was followed by a slow, large decrease with several slow, moderate peaks and bays during the night hours, but no real magnetic disturbance. *D* and *Z* were practically unaffected.

April 17-18—Beginning with a rapid increase of 95 gammas in *H* at $12^h\ 25^m$ GMT, April 17, a very heavy magnetic storm was characterized by a number of very sharp and large peaks and bays in *H* until after 24^h, and it fell to so low a value that the fiber on the *H*-variometer unwound at $20^h\ 56^m$. The night hours were relatively quiet but there was still a mild disturbance during the daylight hours of April 18, and low values were recorded in *H* into the early hours of April 19. *D* and *Z* were sharply disturbed during the peak of the storm, but with only a small range of movement. The range in *H* (obtained from the insensitive *H*-record) was 512 gammas, and the *K*-indices were 6, 8, 7, and 7 for the four three-hour periods beginning with 12^h, April 17.

May 22-24—A short, sudden increase in *H* at $22^h\ 44^m$ GMT, May 22, was followed by only mild disturbance on May 23, but after another short, rapid rise in *H* at $06^h\ 45^m$, May 24, there was a long decrease which reached its minimum at $08^h\ 42^m$ and was followed during the daylight

hours by short, rapid movements and low values in H for more than two days following. D and Z, as usual, were only slightly affected by this moderate disturbance. The range in H was 160 gammas.

June 13-14—At $17^h\ 49^m$ GMT, June 17, there was a sudden increase in H of 120 gammas in five minutes, followed three and a half hours later by a long, slow decrease and low values with slow, moderate movements during the night hours. During the daylight hours of June 14 there were several scattered, sharp peaks and bays of moderate height, the disturbance ending rather abruptly shortly after 21^h, and was followed by only a moderate decrease in H-values during the following night.

June 17—After a short, sudden increase in H at $03^h\ 00^m$ GMT, June 17, only slight disturbance was recorded until after 14^h when several moderate but sharp peaks and bays were recorded, and one deeper bay with its minimum just after 19^h. This mild disturbance ended gradually after 20^h.

PAUL G. LEDIG, *Observer-in-Charge*

WATHEROO MAGNETIC OBSERVATORY

APRIL TO JUNE, 1947

(*Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h\ 43^m.5$ E. of Gr.*)

April 8-10—A moderate disturbance commenced suddenly at $21^h\ 49^m\ 30^s$ GMT, April 8. H increased by 30 gammas in less than a minute and then decreased by 22 gammas in the following two minutes. D swung west by 2′ and then 4′ east by $21^h\ 52^m$. Z increased by 13 gammas and then decreased by 40 gammas in the same time. The movements in all three elements were fairly rapid but not of very great amplitude, and these continued until 16^h, April 9, with only a slight depression in H. For the following sixteen hours the elements were somewhat unsteady and the storm can be considered as ending at 08^h, April 10. Ranges: D, 20′; H, 120 gammas; Z, 79 gammas.

April 17-19—A major disturbance commenced suddenly at $12^h\ 26^m$ GMT, April 17. H was momentarily depressed by 2 gammas and then increased too fast for the spot to record. After this movement of 40 gammas, H further increased by 17 gammas in the next minute. H then began to decrease slowly. D moved 3′ east and then 5′ west in about a minute and a half; simultaneously Z decreased by 16 gammas and then increased by 19 gammas. The movements were slow and of large amplitude for the next seven hours. About 19^h, April 17, the elements began to show more rapid fluctuations. At $20^h\ 27^m$, H began to decrease rapidly, reaching a minimum at $21^h\ 40^m$ after falling by 222 gammas. The next movement in

H was too rapid to record, being an increase of 140 gammas in about two minutes. The fluctuations in all three elements for the next four hours were very rapid, particularly in H. At 02^h, April 18, the variations became less marked, being rapid and of small amplitude from then until 10^h. Moderately disturbed conditions, with fairly large, slow, irregular variations, then prevailed until 23^h, April 18. These were followed by small, rapid fluctuations for the following eleven hours until 10^h, April 19. The movements of the elements were comparatively large and slow during the succeeding eight hours and the disturbance ended at 18^h, April 19. There was a further small, short-lived disturbance on the following day which was probably associated with the same solar disturbance which produced the earlier, larger disturbance. Ranges: D, 39′; H, 280 gammas; Z, 233 gammas.

May 14-16—This storm was not very severe and did not have any very definite commencement. The movements in the elements on May 14 were mainly irregular, small and slow, but at about 22^h 50^m GMT the variations increased in frequency and regularity and decreased in amplitude. These rapid variations continued until 12^h, May 15, with several sudden movements between 07^h and 08^h. Moderate and irregular movements continued until 17^h, May 16, by which time the elements were again nearly normal. Ranges: D, 14′; H, 102 gammas; Z, 74 gammas.

May 22-23—A mild storm of short duration commenced suddenly at 22^h 43^m GMT, May 22. H increased by 8 gammas, too fast for the spot to record. D moved slightly west and then east, while Z changed correspondingly little. Conditions for the next three and a half hours were quiet with very slight movements. Some irregular variations occurred between 02^h 30^m and 11^h, May 23, after which normal conditions prevailed. Ranges: D, 12′; H, 99 gammas; Z, 43 gammas.

May 23-24—A brief storm of moderate intensity commenced quietly at 23^h 42^m GMT, May 23. There were some irregular movements during the next seven hours. Then all three elements swung suddenly at 06^h 45^m, May 24. H increased by 55 gammas in less than a minute, D moved 2′ west and then 8′ east in two minutes, while Z showed an increase of 2 gammas followed by a decrease of 44 gammas. There followed sharp and rapid fluctuations, especially in H, which also dropped appreciably, reaching its minimum at 09^h 07^m. D and Z did not display quite the same violent movements. Recovery began at 09^h 07^m, fairly quickly at first and then more slowly. All the elements were fairly quiet again by 16^h, May 24. Ranges: D, 21′; H, 175 gammas; Z 123 gammas.

June 5-6—A moderate disturbance commenced suddenly at 07^h 26^m GMT, June 5. H decreased 17 gammas and then increased 77 gammas almost immediately, too fast to record. D moved 2′ west and then 3′ east, while Z increased by 3 gammas and then decreased 13 gammas. There-

after H and Z decreased irregularly, Z until $07^h\ 40^m$, H until $08^h\ 35^m$, and both resumed their normal positions by 10^h, except that small variations were superimposed upon each element. These continued throughout the day with decreasing amplitude. A peak in H, and bays in D and Z, between 00^h and 01^h, June 6, may be considered as the final movement of the storm. Ranges: D, 10′; H, 99 gammas; Z, 67 gammas.

June 13-14—A storm of slight intensity commenced at $17^h\ 50^m$ GMT, June 13, when H increased by 15 gammas in three minutes, D moving 2′ east and Z decreasing 11 gammas at the same time. The movements during the next eight hours were slight. Then there were a few more rapid variations between 02^h and 10^h, June 14. H remained slightly depressed at first, and then recovered throughout the day. Conditions had returned to normal by midnight. However, all three elements showed fairly sharp movements between $19^h\ 32^m$ and 21^h, June 14, commencing and finishing rather abruptly. Ranges: D, 13′; H, 142 gammas; Z, 75 gammas.

F. W. Wood, *Observer-in-Charge*

Hermanus Magnetic Observatory

April to June, 1947

(Latitude 34° 25′.2 S., longitude 19° 13′.5 or $1^h\ 16^m.9$ E. of Gr.)

April 2-3—Small crochet-type deflections on the D- and Z-traces at $10^h\ 15^m.5$ GMT, April 2, were followed by abrupt changes in all three elements at $15^h\ 01^m.5$, April 3. The mild disturbance which ensued, died away at about 24^h, April 3.

April 8-9—A very mild magnetic storm began with a sudden commencement at $21^h\ 50^m$ GMT, April 8 (H, 42 gammas), and continued until 16^h, April 9.

April 16-20—Crochet-type deflections at $22^h\ 36^m$ GMT, April 16, heralded the violent magnetic storm which began abruptly at $12^h\ 25^m$, April 17 (H, 40 gammas; Z, 35 gammas). H declined steadily in a succession of well-defined steps (or bays) to a low minimum at $21^h\ 00^m$, April 17, while Z reached its maximum value at $21^h\ 19^m$, and D its extreme westerly reading at $22^h\ 05^m$ on the same day. By 02^h, April 18, the active phase of the storm was past, but recovery to normal was slow and minor activity persisted until about 22^h, April 20. K-indices of 7 and 8 were assigned to the last two three-hour periods of April 17, respectively, while the ranges of the storm were as follows: D, 45′; H, 332 gammas; Z, 311 gammas.

May 6—Crochet-type deflections were recorded on all three traces at $10^h\ 15^m$ GMT, May 6.

May 13-17—Minor activity occurred throughout this period.

May 22-24—A sudden commencement at 22^h 45^m GMT, May 22, was followed by a disturbance of moderate intensity. Maximum activity occurred during the period 06^h-09^h, May 24 (K = 7), following further abrupt changes in the elements at 06^h 45^m. Minor activity continued until the end of the month.

June 1—Large bays (H and Z, 55 gammas) were recorded on all three traces during the first three-hour period, GMT, June 1.

June 5-6—A sudden commencement at 07^h $20^m.5$ GMT, June 5, was followed by a storm of minor intensity which continued until 01^h, June 6.

June 13-14—A storm of moderate intensity, which began with abrupt changes in all three elements at 17^h $49^m.5$ GMT, June 13, was characterized by sporadic fluctuations with quiet periods interspersed. The disturbance abated at 21^h, June 14, although minor activity continued until June 18.

A. M. van Wijk, *Officer-in-Charge*

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Atmospheric Electricity

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DIFFERENTIAL PENETRATION AND MAGNETIC STORMS

BY T. L. ECKERSLEY

(1) *Introduction*

In a letter to *Nature* [see 1 of "References" at end of paper], the writer has already put forward the suggestion that magnetic storms accompanied by a large reduction in the density of the F-layer are caused by neutral streams of charged particles that enter the Earth's atmosphere and are separated out in the ionosphere owing to deeper penetration by the positive particles. According to this idea, the electrons are stopped high up in the F-layer, while the positive ions penetrate to the E-layer, with the result that a strong vertical electric field is set up in the main body of the F-layer between these two systems of negative and positive charges.

This process may be described as one of differential penetration, and there is essentially associated with it an electric field set up between the separated systems of charges. The combined effect of such an electric field and a magnetic field, such as the Earth's field, on the motion of an electron is well known, and the analysis appropriate to the case of an electron moving in the atmosphere above the Earth is given in another paper [2], in which the idea of differential penetration is used to explain the apparent anomalies in the F-layer density that occur in the neighbourhood of the magnetic equator.

Here we shall use the general result that a charged particle in such a system of electric and magnetic fields has a drift-velocity in a direction at right-angles to the plane containing the electric and magnetic fields. If the field due to the process of differential penetration is vertical, the drift is perpendicular to the magnetic meridian plane, and is independent of the mass and the charge of the particle. For both positive and negative charges,

the drift is in a westerly direction. If the electric and magnetic fields are E and H in electromagnetic units, and H_x is the horizontal component of H in the meridian plane, the drift-velocity is (EH_x/H^2) cm/sec and can be very large.

It is the purpose of this paper to describe in terms of this fundamental idea two magnetic storms of great intensity that have formed the subject of two papers by Berkner, Wells, and Seaton. They give a very careful and clear description of the observed features of these storms, but no explanation based on a fundamental understanding of the problem. We shall outline the main steps in the progress of these storms and show that they can be explained by the theory of differential penetration.

(2) *General description of the magnetic storms*

The first storm occurred on April 16, 1938, and the observations made at Huancayo are described in a paper by Berkner, Wells, and Seaton [3]. The second occurred on March 24, 1940, and in another paper Berkner and Seaton [4] describe the ionospheric effects at Huancayo and Watheroo. In both storms there is a rapid decrease in F-layer density followed by an increase in E-layer density. This behaviour was illustrated in the $P't$-record given in the letter to *Nature*, and is characteristic of the ionospheric effects accompanying a strong magnetic storm. It suggests the mechanism of differential penetration, in which the E-layer is ionised by the positive particles entering it.

The storm of April 16, 1938, began at $00^h\ 47^m$ 75° WMT with a sudden reduction of density N in the F-layer, and in the second phase starting at about $02^h\ 00^m$ there is an ionisation of the E-layer similar to that produced by abnormal E, and hiding what is happening in the F-layer. The third phase is, in the main, a recovery, but during this phase, which lasts from $02^h\ 45^m$ onwards, the height of the ionosphere increases enormously, and this increase occurs mainly after the ionisation in the lower layer at 85 km has ceased. The distribution of the density in the F-layer is shown in Figures 10*a*, 10*b*, and 11 of the paper referred to. In these it has been assumed that the electron-distribution in the F-region can be represented parabolically. This parabolic distribution can be fitted to the observed variation of the virtual height h' with frequency f. The constants of the parabola are so selected that the retardations computed from the assumed distribution will yield an $h'f$-curve which agrees with the observed curve to a good degree of approximation. This method, although based on the ray-theory, is very nearly correct when the variation of N is gradual, and gives very good results in this particular case.

The storm of March 24, 1940, occurred in full daylight at Huancayo starting at about 10^h, and nearly at midnight at Watheroo. Most information can be obtained from Figure 13 of the paper referred to, which shows

that the time of start of the violent magnetic effects occurs nearly simultaneously with the reduction of density in the *F*-layer at Watheroo and Huancayo. The magnetic records show a variation before $15^h\ 44^m.8$ GMT at Huancayo (from $13^h\ 44^m$ GMT to $15^h\ 44^m.8$ GMT, when the violent effects started), and these oscillations of the magnetic field are shown in the Figure 13 mentioned above, and are small compared with the main oscillations which occur after $15^h\ 44^m.8$ GMT.

While these small magnetic oscillations are taking place, there is practically no effect on the ionosphere, suggesting that there are two types of magnetic storm, namely, one not affecting the ionosphere and one producing violent changes in the ionosphere. We shall return to this point later in our discussion of the observed effects associated with the storms.

Considering first the effects at Huancayo, the Figures 1, 2*a*, and 2*b* of Berkner and Seaton's paper show very clearly the reduction in *F*-layer density at the local time between $10^h\ 00^m$ and $11^h\ 01^m$ with the formation of an abnormal *E*-layer. At $11^h\ 30^m$ a fresh *F*-layer is formed, and from the rate of growth of it we can get a very good idea of the recombination-coefficient in this layer. They give a value of 1.8×10^{-10} for the recombination-coefficient α, and a rate of ion-production q_0 at the level of maximum density of 231 ions per cc/sec. As we shall see, these results agree closely with a measurement of α which I made some years previously from observations of the night-time decay.

This formation of a fresh *F*-layer according to a normal daytime ionising process was followed at $12^h\ 15^m$ by a very rapid rise in electron-density with subsequent oscillations in height and ion-density at almost regular three-hour intervals, which they explain as due to an incoming abnormal ionisation repeated periodically on a diminishing scale. My own view is that an oscillation is set up in the atmosphere by the incoming neutral stream, and that this produces the changes in density which are observed.

At Watheroo the effects observed are similar. The Figure 13 of their paper shows the rapid reduction of density also occurring at the time when the violent magnetic oscillations begin, and this is accounted for by exactly the same mechanism as accounts for the Huancayo phenomena. The magnetic-storm effects begin at $15^h\ 45^m$ GMT when, as we have supposed, the neutral stream penetrates the ionosphere, both at Huancayo and at Watheroo. From observations of the relative behaviour of the ordinary and extraordinary magneto-ionic components and the unequal spacing of the multiple *F*-echoes, they deduce that there is an upward movement of the ionosphere starting to the north of Watheroo, that is, towards the equator, spreading southwards with time and causing a tilt in the layer. This tilting of the layer is probably only a secondary effect of the penetration of the neutral stream from the Sun.

(3) *Explanation in terms of the differential-penetration theory*

One of the most significant features in the observed effects associated with these magnetic storms is the one referred to above, that at Huancayo the magnetic records show a variation starting two hours before the main onset of the storm, and which is unaccompanied by any significant ionospheric changes. This indication that there are two types of magnetic storm, one not affecting the ionosphere, and one accompanied by large changes in the ionosphere, can be explained in terms of a neutral stream of particles arriving at the Earth. We know that for a constant magnetic field, the curvature of the electron-rays, and that of the positive ions, is the greater the less their speed, so that low-speed clouds are likely to be separated out before they reach the ionosphere. In this case, the electrons will go east and the positive ions west, and there is a cleft in the ionic clouds that produces a ring-stream round the Earth and a consequent magnetic storm.

This type of magnetic storm has been considered by Chapman, and is due to the separation of the charges in the neutral stream from the Sun by the Earth's magnetic field, and to the reaction of this field on the characteristic of the neutral stream, producing a dip and ring in it. It is suggested that the preliminary magnetic disturbance at Huancayo is of this type. The onset of the violent phase of the magnetic storm marks the arrival of a neutral stream of more swiftly moving particles which are moving too fast to be separated out by the Earth's magnetic field before they have reached the ionosphere. On entering the ionosphere, the behaviour of the electrons and of the positive ions depends upon their mean free paths. The mean free path is much less for the electrons than for the positive ions, so that the positive ions penetrate much more deeply into the layer than the electrons.

By this process of differential penetration an electric field is set up between the electrons stopped high up in the F-layer and the positive ions penetrating to the E-layer. As described in the letter to *Nature* referred to in the introduction, such an electric field combined with the Earth's magnetic field will produce a drift of any charged particles situated in them. Such a drift is therefore imparted to the electrons and positive ions forming the main body of the F-layer between the electrons above and the positive ions below derived from the separation of the neutral stream. With an electric field of only one volt/cm the drift-velocity would be of the order of 10^8 cm/sec, so that it is reasonable to suppose that the electrons in the F-layer would be very rapidly swept aside.

This drift-velocity is independent of the mass and charge of the particle, and is in the same direction for both positive and negative charges. There is thus no return force tending to pull the electrons back, such as would have arisen had the positive ions drifted in the opposite direction to the

electrons. When the electric field is acting vertically upwards, as we are supposing here, the drift will be in a westerly direction. The result of the differential penetration will thus be a rapid bodily movement of the F-layer sideways, and if the neutral stream is sufficiently local, the ionosphere may be swept almost clear of negative and positive ions, thus accounting for the rapid reduction in F-layer density which we have seen is associated with the onset of a violent magnetic storm.

The characteristic drop in the critical frequency of the F-layer of the type observed at Huancayo and Watheroo is thus explained, and the rapid increase in height of the layer, on this theory, is due to the removal of the main body of the layer and the exposing of the upper part of the layer in which the electrons in the incoming neutral stream are caught up. The explanation of the reduction in density and the increase in layer height in terms of an expansion-effect would seem to be quite out of the question for such large and rapid changes. The development of the abnormal E-ionisation may be attributed to the penetration into the E-layer of the positive particles from the neutral stream. It might be considered inconsistent that the intrusion of a nuclear cloud into the ionosphere should make a reduction of ions in the F-layer but increase the ions in the E-layer. This is explained on the assumption that in the E-layer the drift is negligible because of the density of molecules there which produce a large number of collisions.

We have, in fact, experimental evidence that when the F-layer is reduced, the E-layer owing to the positive particles in the cloud, is increased. In order to substantiate this theory, a close numerical agreement should be obtained. This close relationship is difficult to get, because it depends on certain initial assumptions which involve a knowledge of the energy and density of the ions in the cloud which we have not got, so that it is impossible to substantiate, by a proof, each individual effect. Although each individual effect is not provable, the fact that the theory gives an explanation of so many of the features observed makes the probability of its fundamental correctness very high.

The drift of the electrons which accounts for the reduction of the F-layer density also explains the magnetic changes occurring at the onset of the violent stage of the storm. The electrons in the F-layer move in such directions as to increase the horizontal magnetic field, corresponding with the normal first phase of such a magnetic storm. The amount depends upon the density of electrical particles in the stream, and no exact numerical computation of this increase of field can be made until this factor is known, though reasonable stream-densities give reasonable increases in H.

Coming now to the question of the recombination-coefficient, we are dealing with a phase of the storm in which the effect of differential penetration is temporarily suspended, and the layer is reforming under more or less normal conditions of ionisation. The interesting feature is that the

observations were made at a time of day near noon when the source of ionisation was almost constant and the layer had to build up from a low value. Some years previously, we made a measurement of the recombination-coefficient α from observations of the density during the night when the normal source of ionisation was removed. Under these conditions, the density-equation is

$$\frac{\mathrm{d}N}{\mathrm{d}t} + \alpha N^2 = 0$$

and leads to

$$\frac{1}{N} - \frac{1}{N_0} \doteq \alpha(t - t_0)$$

and when $(1/N)$ is plotted against t, a straight line is obtained whose slope is the required value of α.

In Figure 1 a plot is shown of the density-changes during the evening of January 27, 1937, derived from measurements of the ordinary and extraordinary critical frequencies. In Figure 2 the corresponding plot of $(1/N)$ as a function of time is shown, and it is evident that there are periods during which the density was decaying according to the assumed law for no ionising source. Between the periods there is evidence that ions do come in, but during these decay-periods a consistent value of α is given as shown by the straight lines drawn in Figure 2. These correspond to $\alpha = 1.8 \times 10^{-10}$ and so agree exactly with Berkner and Seaton's value. These night-time measurements do not give a measure of the ionising source q, and their measurements made under unusual and somewhat rare conditions give information not obtained previously by my own results.

In attributing the ionospheric and magnetic effects of these storms to the differential penetration of a neutral stream of particles, the difficulty arises that the first storm occurred nearly at midnight at Huancayo, and similarly the second storm occurred nearly at midnight at Watheroo. The mechanism by which a neutral stream from the Sun could ionise the atmosphere so far into the shadow-region by a process of differential penetration is not clear. It may be that in this case the positive particles are bent round the Earth by its magnetic field, and that the electrons which tend to be bent away from the Earth are held round the Earth by the attraction of the heavier positive particles. In this case, the separation of the positive ions low down in the ionosphere and of the electrons high up is effected by the magnetic field rather than by an actual differential penetration. It is also possible that on some occasions neutral streams from space, and not from the Sun, enter the ionosphere from above, even during the night-time, and produce the effects we have associated with differential penetration.

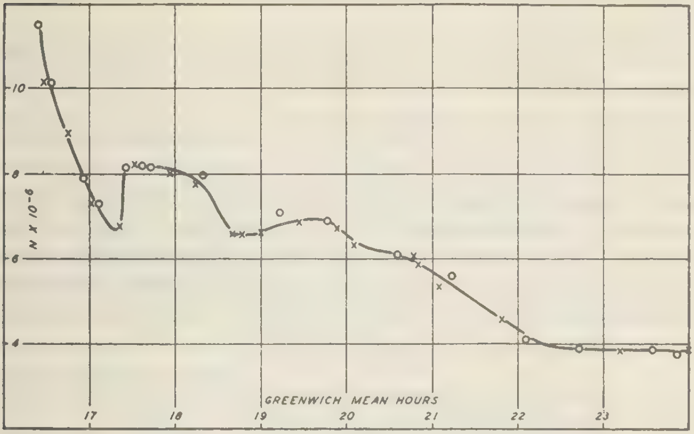

FIG. 1—DENSITY N DEDUCED FROM CRITICAL-FREQUENCY MEASUREMENTS, JANUARY 27, 1937 (x = EXTRAORDINARY RAY, o = ORDINARY RAY)

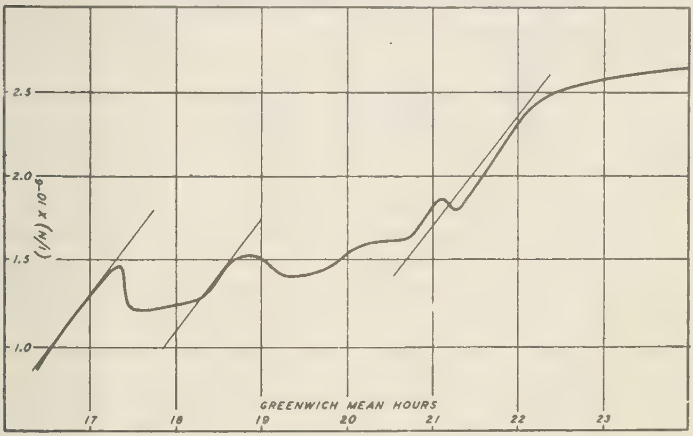

FIG. 2—INVERSE DENSITY (1/N), JANUARY 27, 1937 (STRAIGHT LINES CORRESPOND TO $\alpha = 1.8 \times 10^{-10}$)

Summarising, we may say that there are two types of magnetic storm, both associated with the approach of a neutral stream of particles to the Earth, one caused by slowly moving particles which are separated out into a ring-stream before they reach the ionosphere, and one caused by more swiftly moving particles that penetrate the ionosphere and by a process of differential penetration set up a vertical electric field. This field, combined with the Earth's magnetic field, produces a westerly drift of the ions in the F-layer with a consequent reduction in the F-layer density, combined with the production by the positive ions in the neutral stream of an abnormal

E-layer. The drift-current itself is responsible for the violent change in the Earth's magnetic field.

It is difficult to fill in the details of such a theory owing to lack of knowledge of the density of the incoming stream and of other factors associated with the structure and behaviour of the ionosphere that control the detailed effects of the differential penetration on the electrons in the ionosphere. Observations are often complicated by the superposition of a number of effects, and really a critical analysis of the mass movements of electrons in the ionosphere should be made. But of the fundamental correctness of the process of differential penetration there seems to be little doubt, in view of its success in explaining so many features associated with magnetic storms.

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Weatheroak, Danbury, Chelmsford,
Essex, England, September 18, 1947

NOTE ON "SUDDEN COMMENCEMENTS" AND OTHER SMALL CHARACTERISTIC IMPULSES

By H. W. Newton*

The recent publication by the United States Coast and Geodetic Survey of a first instalment of ¼-size reproductions of daily magnetograms, January to June, 1946, from the Cheltenham Magnetic Observatory, provides some interesting data in connection with "Sudden Commencements" (*SC*) and other small trace-movements that are being studied at Greenwich. In a paper** dated August, 1946, from the Royal Observatory, certain unexpected characteristics of *SC*-occurrence were derived from the Greenwich data 1879–1944.

For two of the results given by the Greenwich analysis, the Cheltenham magnetograms provide a valuable comparison even for the short epoch of six months—a specially active six months, however, embracing some unusual solar phenomena.

These two results are:

(*a*) A tendency for *SC*s recorded at Greenwich-Abinger around 08^h to be "inverted". This inversion of the normal *SC*-impulse appears to be related to a marked forenoon minimum (lowest at 08^h-09^h) in the mean hourly frequency of *SC*s during the 66 years considered. This minimum must presumably be due to a local-solar-time effect, tending to suppress the *SC* or otherwise modifying it, so that it may often escape recognition as such.

(*b*) A close correspondence in time and character of other small characteristic trace-movements as between Abinger and Lerwick. Sometimes for periods of several hours, this similarity phenomenon, more especially in *H*, extends to the smallest trace-details ($\sim$2 gamma) so that the traces from the two observatories are almost replicas of one another. This similarity is usually best seen on days that are relatively quiet or of minor disturbance only, thereby suggesting that the phenomenon is always present but is submerged when there is pronounced activity.

The following notes may be of use to other observatories who are making a day-to-day comparison of their magnetograms with the reproduced ones from Cheltenham for the first half of 1946.

(*a*) *Inverted SCs and the 08^h frequency-minimum*—The normal *SC*-impulse at Greenwich (or Abinger) is $+\Delta H, -$(that is, westerly) ΔD, and

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$+\Delta V$. The positive direction of ΔH appears to be world-wide, but geographical position enters into the direction of ΔD and ΔV. The "inverted" (mirror image) *SC* is $-\Delta H$, $+\Delta D$*, and $-\Delta V$. Inverted *SC*s, only seven per cent of all *SC*s in the extended Greenwich data, are found not exclusively within the general 08^h frequency-minimum given by *SC*s at Greenwich as a whole, but they tend to group therein.

More than half of all the *SC*s at Greenwich have a small preliminary impulse in the opposite direction to the main stroke. The former takes about one-half minute to complete; the latter most frequently three minutes, irrespective of amplitude. The occurrence of the small preliminary impulse, which appears subject to diurnal effects seems worth detailed observation and theoretical investigation. All times of occurrence given in the present note refer to the Commencement (UT) at Abinger of the main impulse, but the small preliminary stroke when present is indicated by $-/+$ for the normal *SC* in *H* or *V* or by $+/-$ for the inverted *SC*, the respective impulses in *D* being *e/W* and *w/E*.

Sudden-commencements or, at any rate, impulses exactly simulating them, do occur at times other than at the onset of many active disturbances. About 35 per cent of all *SC*-movements in the Greenwich data are followed by little or no disturbance, except that *H* usually remains increased for a few hours. Others occur within periods already disturbed. It is important observationally to establish whether these *SC*-like movements are of synchronous world-wide occurrence as are the unmistakable *SC*s preceding many geomagnetic storms.

It should here be remarked that a sample comparison of Abinger and Lerwick magnetograms shows that while the ΔV-impulse of the normal *SC* at Abinger is *plus* it is minus at Lerwick. Forty years ago, Van Bemmelen drew attention to a similar anomaly shown by two magnetic stations in Java (Batavia and Buitenzorg) and also as between Greenwich and Parc St. Maur, Paris. This feature in itself requires investigation.

The present six months of comparative Cheltenham and Abinger data are of course quite inadequate for comparison of hourly frequencies of *SC*s. But the epoch contains five cases of reversed *SC*-impulses at Abinger, all falling within the four hours, $06\frac{1}{2}^h$ and $10\frac{1}{2}^h$ UT. These are reproduced from tracings† of the Abinger magnetograms in Figures 1(*a*) to 1(*e*). Comparison with the published Cheltenham records will show that for Nos. (*b*) to (*e*) the negative (that is, reversed) main ΔH-impulse is represented by a positive impulse at Cheltenham. In (*a*) the movement is lost in the Cheltenham reproduction, but it is known from *Terrestrial Magnetism* [51, 290, 293 (1946)] that at Tucson and Huancayo the abrupt ΔH-impulse was $+69\gamma$ and $+60\gamma$, respectively.

*Figure 1(*b*) shows an exception in which ΔD does not reverse with ΔH and ΔV.

†Tracings for Figures 1 to 3 were made by Miss C. Chapman of the Solar Department staff.

In addition to the above, there were two other $-\Delta H$-impulses within the general 08^h frequency-minimum at Abinger but whose identity as *SC*s was a little doubtful. At Cheltenham the main impulse is again positive.

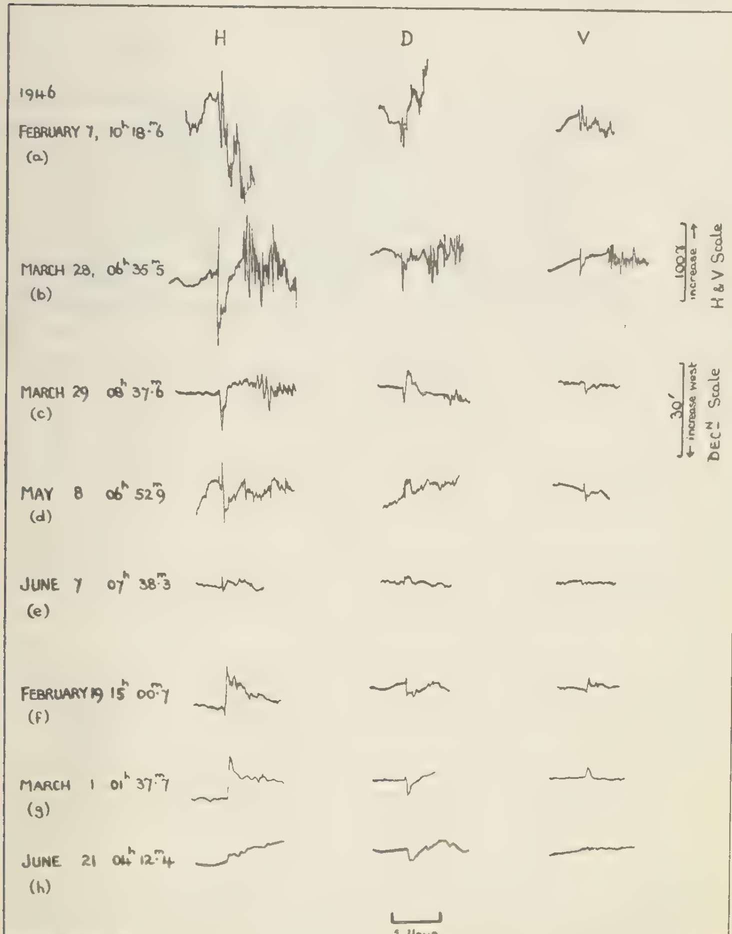


FIG. 1—INVERTED SUDDEN COMMENCEMENTS (SCs) AT ABINGER (a-e); TYPICAL NORMAL SCs (f, g); TINY SC AT ABINGER (h) REPRESENTED BY LARGER TYPICAL MOVEMENT AT CHELTENHAM

Two other *SC*s at $08^h\ 09^m$ and $06^h\ 10^m$, respectively, were positive in ΔH at both places, but the smallness of the amplitudes at Abinger suggested partial suppression there. These four additional cases are as follows:

Date	Began UT	Abinger ΔH	Cheltenham ΔH
	h m	γ	γ
Jan. 3	08 09	+16	+38
Mar. 2	09 53	+11/−30	−2/+20
May 6	07 54	+29/−42	+28
June 4	06 10	+8	+20

It is of interest to examine any SC around 13^h UT, that is, 08^h local solar time at Cheltenham. Here, as it happens, there are only three rather inconclusive cases, namely: February 3, $13^h\ 43^m$ UT; February 19, $15^h\ 01^m$; and June 28, $12^h\ 57^m$. The first, a complex movement at Abinger, perhaps not a true SC, is represented at Cheltenham by a much smaller − + impulse of about $4\gamma/15\gamma$ in H. The second (Fig. 1(f)), a typical SC at Abinger, is probably reversed at Cheltenham, but there is uncertainty owing to partial obliteration of the reproduced trace. In the third case, the (probable) SC at Abinger with ΔH-impulse $-21\ \gamma/+47\gamma$ cannot be seen at all on the Cheltenham trace, but the total suppression of this impulse at Cheltenham is

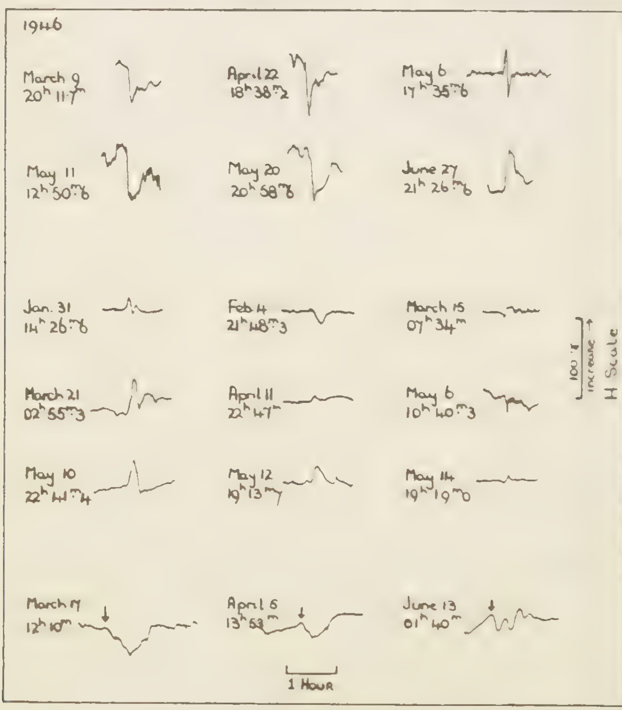


FIG. 2—TYPICAL IMPULSES OTHER THAN CLASSIFIED SCs, SYNCHRONOUS AT ABINGER (ENGLAND) AND CHELTENHAM (UNITED STATES)

left doubtful owing to the proximity in time to the daily changing of the photographic sheet. Reference to the original record would probably be decisive in both the latter cases.

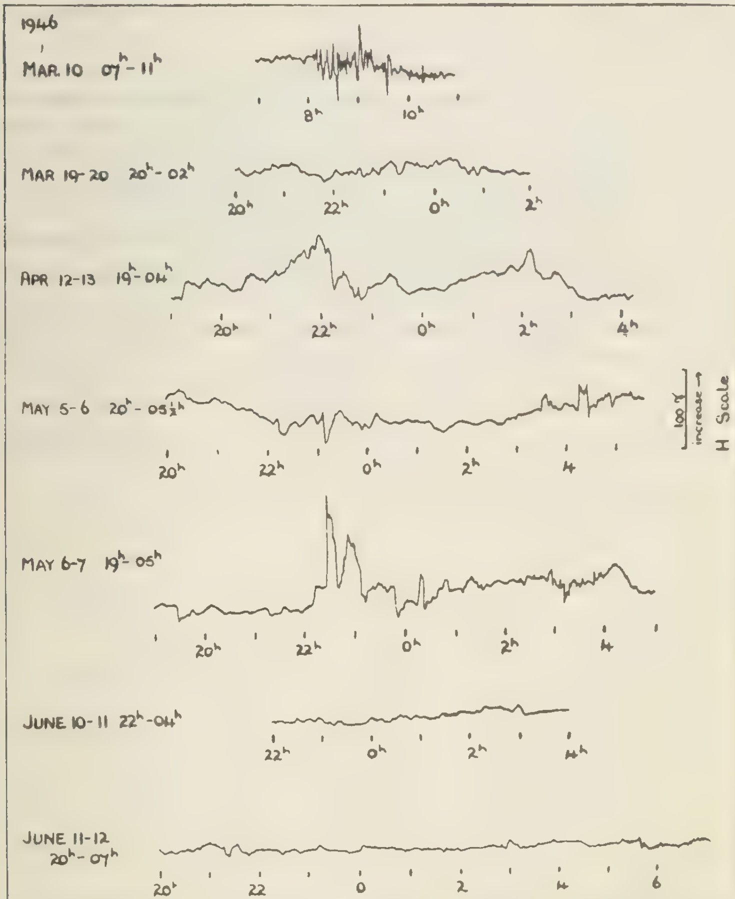


FIG. 3—EPOCHS OF SIMILARITY OF TRACE-MOVEMENTS AT ABINGER AND CHELTENHAM (REPRODUCTIONS ABOVE ARE ABINGER H-TRACES)

(b) *Other characteristic impulses and the similarity phenomenon*—In Figure 2 are shown from the Abinger traces a number of typical movements (other than classified *SC*s) that were closely synchronous and of similar appearance at Cheltenham also. Times are given from the Abinger magnetograms, and in cases of very abrupt impulses have been read from the quick-run record. Removed from their contiguous traces, some of these impulses

look very much like *SC*s. It will be interesting if they are found to be recorded at stations still further removed from Abinger than is Cheltenham (see also Table 1). The last three examples of Figure 2 show movements other than very sharp impulses that are closely similar at Abinger and Cheltenham, as exemplified further in the similarity phenomenon.

Although the reproduced Cheltenham magnetograms do not admit of the comparison of the smallest trace-details (as between Abinger and Lerwick referred to earlier) there is no doubt that epochs of the similarity phenomenon (as it is here called) do exist as between Abinger and Cheltenham. The latter observatory is 93° of geomagnetic longitude west of the former and 4° of geomagnetic latitude southwards.

Figure 3 shows the Abinger *H*-traces (in which element the similarity chiefly appears) for seven of these epochs during the first half of 1946. Each includes strokes and other smallish features that are nearly identical at the two places. The fifth epoch includes what appears to be a very large *SC* commencing at $22^h\ 27^m.5$.

Table 1—*Abrupt impulses common to Abinger and Cheltenham, 22^h, May 5, to 09^h, May 6, 1946*

Date	Time, UT	ΔH, Abinger	ΔH, Cheltenham	Ratio (C/A) [main stroke]	Type
	h m	γ	γ		
May 5	22 12	−20	−30	1.5	Small bay
	23 08.9	−42	+12/−55	1.3	Stroke (*SC*?)
May 6	03 30.2	−4/+27	−3/+30	1.1	*SC*
	04 17.0	+40	+64	1.6	*SC*
	07 54.4	+29/−42	+28	0.7	Double stroke
	10 40.3	−26	−25	1.0	Stroke
	17 35.6	+37/−64	−5/+24/−30	(0.5)	Oscillation
	19 24.7	−27	−18	0.7	Stroke
	22 11.1	+28	−4/+38	1.4	Stroke
	22 27.6	−4/+125	−20/+200?	1.6	*SC*
	23 48.7	−44	−66	1.5	Stroke
May 7	0 17.6	+41	+53	1.3	Pinnacle
	0 20.9	−50	−43	0.9	
	1 13.1	+24	+32	1.3	Stroke
	3 10.4	−35	−39	1.1	Stroke
	8 26.7	−33	−30	0.9	Stroke

The three-day epoch of May 5–7 is a very remarkable one embracing a large number of sharp impulses that can be identified at the two observatories. Fifteen of these impulses are listed in Table 1, so that magnetograms from even more widely separated stations may be compared. It will be noted that the mean ratio of the ΔH-impulses for Cheltenham/Abinger

is approximately unity, as was found for similar impulses common to the Abinger and Lerwick records, whereas the mean total range in H during active disturbances was five times greater at Lerwick than at Abinger.

In passing, it may be noted that at this time the region of the Sun which had contained the great sunspot of February had returned to the disk for the third time and was approaching the west limb. Later, in the same general region of the Sun the giant active spot-group of July developed.

To conclude: Reproductions by one or other method of magnetograms from various observatories can be put to immediate use in obtaining primary data of *SC*s which present some puzzling features in their occurrence as viewed from a single observatory. The extent to which the "similarity phenomenon" is shown by widely separated observatories also requires such observational data. It would appear that besides the unmistakable *SC*s, there is a class of analogous rapid impulses, which, if not found to be of synchronous world-wide occurrence, are recorded over wide areas of the Earth. Coordinated data of all these possibly related phenomena must have an important impact on theory.

Royal Observatory,
Greenwich, August 6, 1947

(See also pages 451, 495, and 522)

PROVISIONAL SUNSPOT-NUMBERS FOR JULY TO SEPTEMBER, 1947

(Dependent on observations at Zurich Observatory and its stations at Locarno and Arosa)

Day	July	August	September
1	140	138	237
2	125	155	196
3	167	210	236
4	155	220	181
5	147	192	204
6	160	204	206
7	177	257	243
8	131	251	284
9	160	299	242
10	165	313	206
11	144	320	191
12	145	298	194
13	180	295	156
14	210	286	150
15	220	271	137
16	210	262	122
17	213	215	156
18	179	186	140
19	228	150	105
20	212	126	93
21	225	103	98
22	214	90	98
23	195	80	106
24	179	82	128
25	147	104	150
26	151	92	173
27	128	124	197
28	130	151	194
29	122	181	213
30	121	208	229
31	146	217	
Means........	168.6	196.1	175.5
No. days......	31	31	30

Mean for quarter July to September, 1947: 180.2 (92 days)

Swiss Federal Observatory,
Zurich, Switzerland

M. Waldmeier

THE MAGNETIC DIURNAL VARIATION OF THE HORIZONTAL FORCE NEAR THE MAGNETIC EQUATOR

By J. Egedal

In a communication to the Edinburgh Meeting of the Association of Terrestrial Magnetism and Electricity, Dr. A. G. McNish has given the results from an analysis of the diurnal variations of the magnetic elements for five observatories in the Western Hemisphere. In this analysis also the diurnal variations at Huancayo are used. McNish points out that the establishment of the observatory at Huancayo "has led to the discovery of magnetic diurnal variations markedly different from those expected for such a region." In using these new data from Huancayo the analysis of McNish has become of great value. McNish makes it clear, that older analysis of magnetic diurnal variations are not able to represent the diurnal variations at Huancayo, and that "more terms would have been needed to fit completely the horizontal components". These statements of McNish may be illustrated by the figures in Table 1 where the range of the north component at Huancayo is given

Table 1—*Range of north component at Huancayo*

	γ
Observed	105
McNish	77
S. Chapman	36

The value obtained from the analysis of McNish is considerably lower than the observed value because a too small number of terms have been applied, and the value from the analysis of S. Chapman is still lower because sufficient data were not available when the analysis was made. However, even if some more terms had been used in the analysis of McNish, so that the diurnal variations at Huancayo could be represented in a satisfactory way, it is not certain that the diurnal variations at an observatory lying, say 300 km, north or south of Huancayo could be represented in a satisfactory way by the derived function. This doubt is based on an examination of the total ranges of H corresponding to mean sunspot-number for observatories lying near to the magnetic equator. The range of the diurnal variation of H is found as the mean of the ranges for all days for September, 1913 (sunspot-minimum) and 1918 (sunspot-maximum) for Alibag, Antipolo, and Kodaikanal. Further is used: For Madras the total range of the means for September 1851-1855, and for Huancayo the total range of H for September 1934 (104 γ) augmented with 20 per cent to 125 γ in order to obtain the range corresponding to mean sunspot-number.

Further the magnetic inclination is used for the indication of the distance of the observatory in question from the magnetic equator. In Table 2 are given names of observatories, their geographic coordinates, geomagnetic latitude, magnetic inclination, and total range of H for all days (September) and for mean sunspot-number.

Table 2—*The total range of diurnal variation of H*

Station	φ	λ	Geomag. latitude	Mag. incl.	Total Range of H
	°	°	°	°	γ
Alibag	18.6 N	72.9 E	9.5	24.4	38.5
Antipolo	14.6 N	121.2 E	3.3	16.2	45.5
Madras	13.1 N	80.2 E	3.1	7.6	49.5
Kodaikanal	10.2 N	77.5 E	0.6	4.3	82.5
Batavia	6.2 S	106.8 E	−17.6	−31.6	52.3
Huancayo	12.0 S	284.7 E	−0.6	2.3	125

In Figure 1 the range for H is given as abscissa and the magnetic inclination at the observatory in question as ordinate.

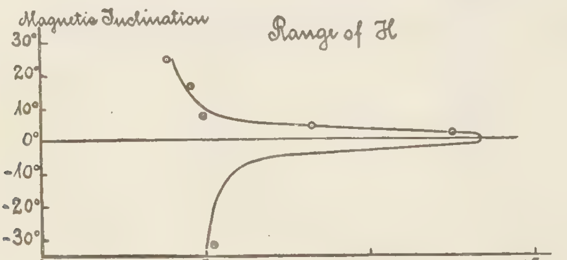


FIG. 1

The full curve of Figure 1 is drawn as far as the values permit symmetrical to the line corresponding to magnetic inclination = 0°. From Figure 1 it will be seen that the values for Kodaikanal and Huancayo are in accordance with one another. If geomagnetic latitude is used as ordinate the two values are not in accordance with one another. The great augmentation of the range of H in a narrow zone near the magnetic equator seems to indicate that the variation is caused by a varying electric current flowing in a very narrow zone of the atmosphere above the magnetic equator. The deviations from the normal value for Kodaikanal and Huancayo indicate that the current is flowing in a height of about 100 km. Such a current also produces a diurnal variation in the vertical force (Z) to both sides of the magnetic equator. Even if the diurnal variation of Z in these regions is remarkably great, it seems too small in relation to the values for H, but,

when the effects of the currents induced in the Earth are considered, there seems to be a better accordance between the variations of the two elements. In the above mentioned communication McNish points out that at places where the magnetic equator is situated far from the geographic equator an augmentation of the normal diurnal variation will occur. This may explain the augmentation of diurnal variation at Huancayo lying between the two equators, but for Kodaikanal lying to the north of both equators and about 200 km from the magnetic equator the explanation does not seem appliable.

According to P. O. Pedersen* a difference between the conductivity of the upper atmosphere at Huancayo and Kodaikanal will exist on account of the difference between the values of H at these places. The difference between the ranges of H at these two places may be explained in this way, but the difference between the ranges at Kodaikanal and Madras certainly does not originate from a difference in the conductivity at these last-mentioned places.

It is obvious that more data concerning the range of H at the magnetic equator are needed, as well at places where the distance between the magnetic and geographic equator is greatest as near the places where the two equators are crossing each other.

In conclusion the author wishes to thank J. Olsen and A. Lundbak for valuable suggestions and discussions in connection with the preparation of the present communication.

Det Danske Meteorologiske Institut,
Copenhagen, Denmark, October 3, 1947

*P. O. Pedersen, The propagation of radio waves, Danmarks naturvid. Samfund A. Nr. 15 *a*, 149, Copenhagen (1927).

LETTERS TO EDITOR

(See also pages 448, 495, and 522)

SOLAR AND MAGNETIC DATA, APRIL TO SEPTEMBER, 1947, MOUNT WILSON OBSERVATORY

During April (and also March) the Earth's magnetic field was remarkably calm for an equinoctial month in which very large spots were present on the Sun. Although the huge complex bipolar group, No. 8478, which crossed the solar disk from March 30 to April 14, covered a large area and had complex magnetic fields, it produced only a few flares, all of those observed at Mount Wilson being small. This group, a return of the large spot of March, was the largest ever recorded, even surpassing the great group of February, 1946.

The magnetic storm of April 8-9 occurred when the great group was 1.8

TABLE 1—*Magnetic storms*

Greenwich civil time						Range in H
Beginning			Ending			
1947	*h*	*m*	*d*	*h*	*m*	γ
Apr. 8	21	50*	09	12	..	117
17	12	26*	18	22	..	286
May 22	22	45*	24	16	..	167
June 5	07	25*	06	02	..	181
13	17	50	14	22	..	174
July 17	17	24*	19	03	..	205
Aug. 15	09	50*	20	16	..	280
22	09	11*	23	08	..	285
Sep. 2	23	28	04	07	..	245
14	04	..	15	22	..	140
24	00	..	25	22	..	200

*Sudden commencement.

days past the central meridian; that of April 17-18 when it was on the invisible side of the Sun. The magnetic storm of May 22-24 began when Group 8568, the most active group on the Sun at that time, was 0.3 day east of the central meridian. An aurora was visible at Mount Wilson during this storm. During the storms of June 5-6 and 13-14, the most active group was 8611, which was four days east on June 5 and four days west on June 13. On July 17-19 three large groups were present. Two of these, Mount Wilson 8706 and 8707, were close together on the central meridian 7° north of the center of the solar disk. The third, 8715, was 38° east, in latitude 12° north.

On August 15 the northern spot-zone was active from 44° east to the west limb. The region near where 8706 and 8707 had been in July was about 35° west and included groups 8767, 8768, and 8769; the region of 8715 which was near the central meridian contained groups 8774 and 8776. On August 22, with the exception of group 8874, which was on the west limb, no large or active groups were present.

Many days in September were magnetically active, but the activity did not resemble that of typical magnetic storms. The days with the largest ranges are indicated in Table 1. Groups 8797, 8798, 8802, and 8803, all in the southern hemisphere, were near the central meridian on September 2. An active group No. 8807 passed within 4° of the center of the solar disk on September 6. None of the eleven groups on September 14 was exceptionally large or active. On September 25 the large active bipolar group 8833 was on the central meridian 10° north of the center of the disk.

CARNEGIE INSTITUTION OF WASHINGTON,
MOUNT WILSON OBSERVATORY,
Pasadena 4, California, September 23, 1947

SETH B. NICHOLSON

A PROPOSED AURORAL INDEX-FIGURE*

By I. L. Thomsen

Introduction—Even a casual observer of an auroral display notices changes either slow or fast, of what may be termed intensity or activity. Assuming cloudless skies, the complete description of a display would require trained observers to record continuously throughout the dark hours. Most of our knowledge of the Aurora Australis as seen from New Zealand, is obtained from numerous reports from voluntary observers, with all degrees of skill. By virtue of the human factor in the case of voluntary observers, some observations may be continuous and intense for perhaps two or three hours, while others may be "spot" observations merely stating that an aurora was seen at a certain time. It was with a view to trying to obtain a clear picture of a whole display from such a series of observations that the present discussion arose.

Assuming a clear picture of the whole display can be obtained, we then require some indication of what might be termed the intensity of the display, either for purposes of correlation or for comparison of displays, one with another, separated perhaps by several years. For either of these purposes a good index-figure for auroral activity would be invaluable, but it is beset with many difficulties. The method of Currie and Jones [see 1 of "References" at end of paper] would seem to cover a good many requirements, but it probably depends more on having an established auroral station with trained observers, rather than the present New Zealand arrangement. One advantage of the New Zealand arrangement is that to a large extent the effect of cloud will be reduced to a considerable extent owing to the large scatter of points of observation.

The chief characteristics of an aurora observed from one station may be broadly listed as follows: (1) Light-intensity and colour; (2) auroral forms; (3) movement; (4) area of display on the celestial sphere; and (5) duration of display.

It would be desirable to combine all these factors in some way into an index-figure, for the complete evaluation of an auroral display; but so complex would the task of observing become, as well as the analysis, that a simple compromise might prove more economical and useful.

Previous scales or indices—The difficulty of assigning some number to a display to indicate its importance is recognised by the scales which have been in use.

In analysing observations at the Blue Hill Observatory from 1885 to

*Presented before Physical Sciences Section, Royal Society of New Zealand, New Zealand Science Congress, at Wellington, May 20-23, 1947.

1940, Stetson and Brooks [2], adopt a classification of brightness as follows: Faint aurora, 0; medium brightness, 1; brilliant aurora, 2. This does little more than say that an aurora occurred. A system on much the same lines seems to have been adopted by the United States Antarctic Expedition to Little America in 1940 [3], when four degrees of intensity were used: Faint; moderate; bright; brilliant. This followed the scheme adopted by Davies [4] on the 1929 Byrd Expedition, which was: 0, no aurora; 1, faint; 2, moderate; 3, bright; and 4, brilliant. He states that this was the same scale that was used by Sverdrup on the *Maud* Expedition in the Arctic and also on other Antarctic expeditions. He adds significantly: "As intensity is an eye-estimate only, it is not easy to compare intensity-records of different expeditions."

In a preliminary summary of observations at Meanook, Canada, 1932-33, Vestine [5] uses an arbitrary, graduated brightness-scale as seen by eye from zero to four as follows: 0, an auroral form so weak in intensity that it was barely distinguishable; 4, reserved for only a few of the brightest displays based on mental comparison, with casual past observations of aurora. It will be noticed that there is no definition of intensities 1, 2, and 3, and that intensity 4 is entirely dependent on experience over a long period of time. It must suffer more than anything else on personal estimation.

For the visual observations made at Saskatoon, Canada, 1932-33, Alty and Wilson [6] again adopted a similar scale as follows: 0, no aurora visible; 1, faint; 2, moderately bright; 3, bright; and 4, very bright.

A much finer division of such scales was used by Backhouse [7] who adopted the following: 1, very faint indeed; 2, very faint; 3, faint; 4, rather faint; 5, rather bright; 6, bright; 7, very bright; 8, very bright indeed; and 9, extraordinarily bright.

Such scales as these, appear to concern themselves with only brightness, which leaves a good deal to the personal opinion of the observer and certainly presupposes a certain amount of experience. No account seems to be taken of auroral form or activity. A scale proposed by D. la Cour [8] combines in some degree brightness and auroral form, and from this scale we derive the approximate relationship that brightness is a function of form.

Scale	Intensity	Features	Exposure-time
0	Nothing to be seen		
1	Faint	Faint beams, arcs, and remnants	1 min to 2 min
2	Moderate	Quiet regular arcs	20 sec
3	Bright	Ordinary beams and draperies	7 sec
4	Very bright	Bright draperies	1 to 2 sec

The last column gives the approximate time of exposure necessary to obtain photographs by means of an ordinary auroral camera. This scale has been

used in a fairly flexible manner up to the present time by the Carter Observatory. Following the precepts of Geddes, scale 4 has generally been reserved for displays in which coronas or rays near the zenith occur, or where intense flaming follows a highly active rayed arc, or evidence of the very red types of auroras.

Variable nature of an auroral display—The fact that an auroral display is by no means a static phenomenon is obvious to any observer, and has been clearly recognised in the discussions by Currie and Jones [1] and Davies [4] in their schemes for deriving auroral character-numbers.

That a display generally follows a certain sequence is recognised in the setting out of "The photographic atlas of auroral forms," and was stated clearly by Geddes [9] for the Aurora Australis. The sequence of forms noted by Geddes was

$$G \rightarrow \begin{matrix}(HA)\\(HB)\end{matrix} \rightarrow \begin{matrix}(RA)\\(RB)\end{matrix} \rightarrow D \rightarrow C \rightarrow F \rightarrow \begin{matrix}(DS)\\(PS)\\(R)\end{matrix} \rightarrow HA'$$

An examination of this sequence in conjunction with la Cour's table, shows a general rise and fall in activity. Hitherto, the scale-value for any display on a given date, has been the maximum reached and has taken no account of duration in any way. Thus we may have a glow lasting for an hour or more, which will be put down as scale 1, whereas a few bright rays may appear for 15 minutes and be put down as scale 2. In practice, at the Carter Observatory, the latter kind of display would be indicated by 1, but it is quoted as an example of what should happen by following this intensity-scale exactly. Again we may have a display in which scale 4 is reached once, and another in which scale 4 is reached twice. In a summary list, both displays will appear to have been equal, whereas it is obvious that they are not. To try to obtain a character-figure for each hour as suggested by Currie and Jones, is a considerable improvement, but on the other hand the auroral activity can increase tremendously in a matter of five minutes. In many cases, a good observer will record activity-changes from minute to minute, and often half or quarter minutes are needed.

The terms "activity" and "intensity" of an auroral display are liable to be used rather loosely and become confusing. Intensity should normally be used in reference to the brightness of an aurora, while activity refers to movement and change of form. In combining the two one may perhaps speak of the "importance" of an aurora. Owing to the more easily used word "intensity", importance is that which is implied in all that follows.

To derive a more suitable scale for one station, the following assumption is made: The intensity of any auroral display at any instant, is directly proportional to the auroral form in evidence.

General classification of auroral forms—Apart from peculiar or special

auroral forms, we may divide the general forms into four great divisions, each of which includes several sub-divisions.

General form	Detailed form	Symbol
Glows	Glow	G
Arcs and bands	Homogenous arc	HA
	Pulsating arc	PA
	Homogenous band	HB
Phenomena with rays	Ray	R
	Rayed arc	RA
	Rayed band	RB
	Drapery	D
	Corona	C
	Flaming corona	FC
	Flaming	F
Surfaces	Pulsating surface	PS
	Diffuse surface	DS

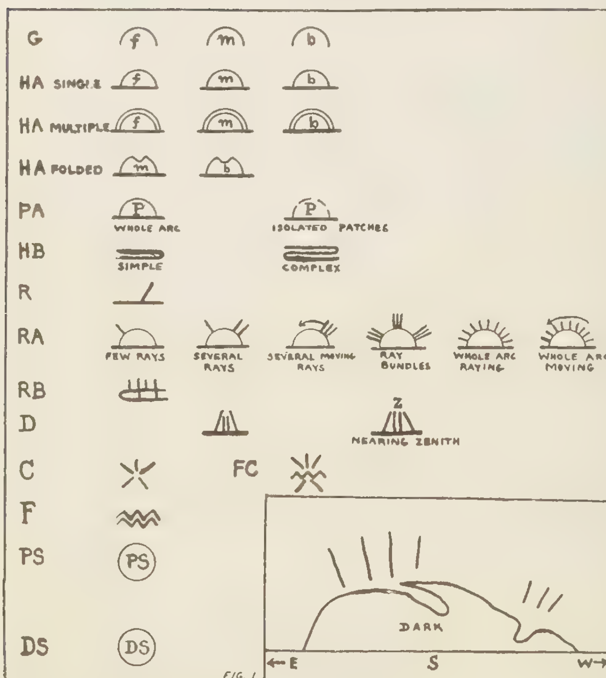


FIG. 1—SUGGESTED SYMBOLS FOR PRINCIPAL AURORAL FORMS

FIG. 2—FOLDED HA, CAMPBELL ISLAND, APRIL 15, 1943 (10 MINUTES), BY J.H. SORENSEN

The detailed forms can be again sub-divided, for observation shows that glows can vary in brightness, rayed arcs have a great variety of forms due to the activity of the display, and so on. In Figure 1 are illustrated suggested symbols for the principal auroral forms, and their use is explained below. In general these symbols are merely simply little pictures of the obvious auroral forms, and have the ability of presenting the chief auroral form immediately to the eye. The symbols *f*, *m*, and *b* refer to "faint", "moderate", and "bright", respectively. In the case of the rayed arcs, flexibility can be used with the symbols. For example, in cases of a few rays, the ray-symbol can be placed on the eastern or western part of the arc, as actually observed. The arrow for moving rays can be reversed to indicate rays moving from east to west or vice versa; and in the case of rays starting from east and west simultaneously, two direction arrows could be used. Such flexibility in the use of the symbols will often serve as a broad check when observations from many stations are being considered.

The folded HA does not seem to have been observed in the Aurora Australis until observations were commenced at Campbell Island. While it is accompanied with rays, it is still not the usual RA-form, but appears to be a type between the usual HA and RA and showing much movement. The general form is shown in Figure 2, extracted from manuscript notes by J. H. Sorensen. On several occasions he noted the fold moving from east to west, but H. R. Atkinson on the other hand has frequently noted the reverse movement [10].

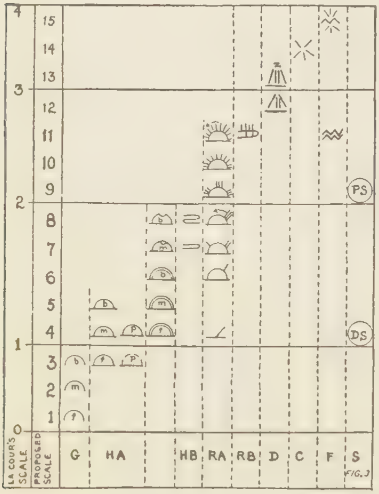
Mention might also be made here of a generalisation on the flaming aurora, made by Sorensen, from observations at Campbell Island. Near the end of a display, the "wave-length" of the flames is small. They are numerous and rapid and last for a considerable time. On the other hand they can be seen with larger "wave-lengths", which might be described as sheets of flame. They are then not so numerous, but one-third to one-half the sky can be illuminated at one time with one "flash." They then change to the smaller "wave-length" type. However, as there are not yet a sufficient number of detailed observations of flaming auroras, it is felt that at present no sub-divisions should be made. It is thought that if ever it is necessary to sub-divide this type, it can be fitted into the suggested scheme.

Scheme for auroral intensity at a single station—The following scheme for relating intensity to auroral form is suggested:

la Cour's scale	Proposed scale	Auroral forms
0-1	1	G (faint)
	2	G (moderate)
	3	G (bright), HA (single, faint)
		PA (isolated patches)
1-2	4	HA (single, moderate)
		PA (whole arc)
		HA (multiple, faint), R, D^{f}

la Cour's scale	Proposed scale	Auroral forms
	5	HA (single, bright)
		HA (multiple, moderate)
	6	HA (multiple, bright), RA (1 or 2 rays)
	7	HA (folded, moderate)
		HB (single, moderate)
		RA (few rays)
	8	HA (folded, bright)
		HB (complex, bright)
		RA (many, moving)
2-3	9	RA (bundles), PS
	10	RA (whole arc raying)
	11	RB, F, RA (whole arc raying with movement)
	12	D
3-4	13	D (near zenith)
	14	C
	15	FC

It may be argued that the sub-divisions of the original scale of la Cour's should have been equal in order to produce symmetry. In a typical display, however, it is obvious that the curve of intensity with time is not symmetrical with respect to any maximum axis, and the sub-divisions have been made with this idea in view. Thus the change from a glow to any of the arcs can take place fairly quickly, after which there is a variety of changes before we come to draperies or rays near the zenith. The jump to a corona can be quite sudden, after which the intensity although falling can remain fairly high for a considerable time, sometimes hours, and at other times everything fades within a few minutes.



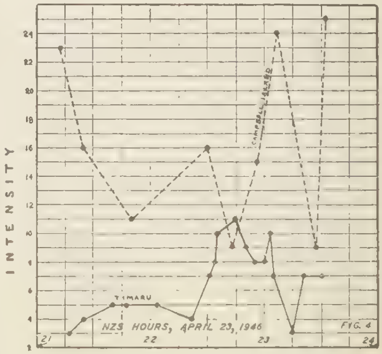


FIG. 3—SUGGESTED SCHEME FOR RECORDING PRINCIPAL AURORAL FORMS BY SYMBOLS

FIG. 4—GRAPHICAL METHOD OF PLOTTING AURORAL INTENSITIES

In Figure 3 the scheme is set out with the proposed symbols and can perhaps be better appreciated than from the above table. Assuming the horizontal line to represent any time-interval during a complete display, it will be seen that the arrangement of symbols gives a fairly close picture of the rise and fall of activity.

Example—As an example of the rapid evaluation of the general activity of an auroral display from a report, the observations of A. F. Jones of Timaru, on April 23, 1946, are taken. The report as received was as follows:

N.Z.S.T. *h m*	
21 17	White auroral arc stretched from the horizon below Alpha Pavonis up to 5° above the horizon and down to the horizon below Caelum.
21 25	Arc (HA) brighter center below Alpha Eridani—higher arc extended further in the west.
21 40	Arc brighter—sky glow above arc and sky dark below arc.
21 47	Arc brighter (?), greenish tinge (?).
21 55	Arc bright; Alpha Grus seen below arc.
22 04	Arc still bright.
22 22	Arc appeared fainter—moon rising—a few clouds low in the southwest.
22 31	Faint ray from arc up to Delta Tucanae; other rays below and west of Alpha Pavonis. Cloud in southwest below arc.
22 34	Ray passed through Chi Eridani to the south of Beta Reticuli up to Beta Mensae. Ray up to Alpha Pavonis, others below Pavonis.
22 35	Broad ray up to Delta and Epsilon Reticuli moved to the west of Epsilon Reticuli. Thin ray up to Alpha Tucanae. Ray to west of Beta Tucanae stretched up to Nubecular Minor. Thereafter there were many rays along the whole length of the arc with the center of activity below Reticulum.
22 45	*Maximum.* Bright rays between and up to Nubecular Major and Delta Pictoris. The rays were green at their bases. Other rays (not so bright) right round to Columba. Little activity east of south.
22 50	Fewer rays—mostly below Alpha Carinae.
22 55	Glow above clouds in the s-sw much fainter; bright patches as though tops of rays stretching up to the arc. Bright ray up to 1° west of Alpha Hydri; moved to the west.
23 00	Renewal of activity below Reticulum.
23 03	Arc still seen in Grus. Passed above Beta and below Alpha Grus. Below Alpha Hydri a bright green ray was seen through a gap in the clouds to reach up to the arc.
23 05	Rays low in southwest seen through clouds.
23 15	Arc diffuse appeared as a glow from the horizon in Grus to below Columba, the center being 1° to 2° below Alpha Eridani.
23 20	Arc quiet west of south, faint rays east of south. A ray stretched up from the arc between Alpha and Beta Grus. Another brighter ray stretched up through Gamma Tucanae to the south of Delta Tucanae; moved to the right.
23 25	Glow brightest in the Grus-Phoenix region—rays brightest there. Faint rays above the whole length of the arc, from Grus to Columba.
23 30	Glow fainter—a few bright rays. Observing ceased.

From such a report as this it is possible if desired to reconstruct the important aspects of the display on the celestial sphere, and fairly good data on bearings and altitudes of some of the auroral forms can be deduced. For our purpose of a rapid analysis of activity however two methods can be used.

In the first method a horizontal line is drawn, divided into a time-scale, and the appropriate symbols inserted on the line. The second method is to plot intensities in the usual graphical method, and is shown in Figure 4. From this particular report, attention should be drawn to two interesting details. First it will be noticed that in the latter half of the period of observation, one gets the impression that while the auroral forms are visible, they are not of great brightness, due no doubt to the presence of Moon and clouds. Since intensity has been taken as a function of form, the graph does not fall in level due to extraneous causes. Second, the observation at $23^h\ 03^m$ should be noted. Here we have a HA and the observer specifically points out that a ray was observed coming up to and meeting the HA. This is interpreted as being produced from a RA below the horizon, and is supported by the appearances of this aurora as seen from Campbell Island. Thus for this particular time, the intensity is taken as 4 for the HA plus 6 for a RA, giving a total intensity of 10.

This brings us to the problem of dealing with intensities when several auroral forms are in the sky at the same time. For the great majority of New Zealand displays this problem does not arise, but it becomes important as we approach closer to the auroral zone for such a station as Campbell Island. The method proposed of dealing with such cases is best shown by taking an example, which is from the report of the same display as quoted above, and taking the same period of time. On this occasion, at Campbell Island, the observers reported what they called a ray stretching from the east through the zenith to the west. This, from its persistence, and the general description is taken to be actually a high-altitude homogeneous arc of the type described by Störmer in his memoir on "Remarkable auroral forms" [11]. The following table is not the exact copy of observations but the interpretation deduced therefrom.

Plotting these on the same graph with the Timaru observations it will be seen that the same general trends of activity are approximately indicated, and that the level of activity is very much higher, as should be expected for a station of much higher geomagnetic latitude. The great difficulty in comparing the two stations closely is the small number of times noted from Campbell Island. Twenty minutes between records of events is much too long.

The main discrepancies in the tendencies of the two graphs are at the commencement, and at $22^h\ 45^m$. An attempted explanation of this leads to interesting results. It will be noted that at the commencement of this

N.Z.S.T.	Auroral form	Intensity assigned	Total intensity
h m			
21 12	HA (high altitude) at zenith	5	
	C (south of zenith)	14	
	HA (in south)	4	23
21 25	HA (double, in south)	5	
	HA (high altitude)	5	
	G (in north)	2	
	DS (in north)	4	16
21 50	HA (high altitude)	5	
	DS (in north)	4	
	G (in north)	2	11
22 30	RA (in south)	7	
	DS (in north)	4	
	HA (high altitude)	5	16
22 43	HA (high altitude)	5	
	DS (in north)	4	9
22 56	HA (high altitude fading)	4	
	DS (north)	4	
	RA (north)	7	15
23 07	RA (north)	10	
	C	14	24
23 27	RA	9	9
23 32	C	14	
	D	11	25

period, all the activity is in the southern sky at Campbell Island, and invisible from Timaru, where only an HA is seen in the south. The arc slowly gets higher and brighter at Timaru, and at $21^h\ 50^m$ Campbell Island has lost all activity in the south, but sees a glow and diffuse surfaces in the north. From $22^h\ 00^m$ to $22^h\ 30^m$ the arc is bright at Timaru with the commencement of raying, by which time Campbell Island has a RA in the south, which is obviously invisible from Timaru. Here then are two separate rayed arcs. At $22^h\ 45^m$, the RA is at a maximum from Timaru, but Campbell Island has lost all activity in their southern sky and has mainly a DS in the north with no trace of RA. It would seem that after this time, the RA seen from Timaru moved south again, gradually losing intensity as seen from there, but was then seen in the north at Campbell Island. The Campbell Island records are sadly lacking in sufficient detail to make a closer comparison than this, but it does tend to show that during an intense display there are successive "waves" of auroral arcs of some kind or another, from the auroral zone up to the northern limit of the display. The discrepancy at the end of the graph is difficult to interpret as the Timaru observations ceased just before the next burst at Campbell Island, but it seems likely that this is the southward receding arcs which would not be visible from Timaru.

From the Timaru observations, it is seen that this method of indicating activity is complete for the period of observation. It also shows the difficulties encountered in assigning an index to the display as a whole. On la Cour's scale, the maximum as observed at this station is between 2 and 3, and would possibly be catalogued under the old scheme of the Carter Observatory, as an aurora of intensity 2. The graph shows, however, that the intensity was, on the new scale, 8 or above, for only 25 per cent of the period of observation. Supposing that another display had been between 8 and 10 for 75 per cent of the same period of observation, it would seem unreasonable to suggest that both displays were equal merely because they had reached the same maximum. Moreover, while good observations were made during the period concerned, it does not give the full story of the display for it is known that the full duration was from 19^h 15^m (NZST), April 23, to 04^h 45^m, April 24, 1946.

Use of a large number of stations—It is obvious that the advantages of collecting a large number of observations from observers scattered over an area are as follows: (1) There is more chance of determining the duration of a display; (2) the cloud-factor is to a considerable extent reduced; and (3) frequent checks are available between observers. As against these advantages, however, there is the complication that in an area such as New Zealand, as we approach the auroral zone, the intensity of each station rises for any given display. Thus taking the display of April 23, 1946, again, in the earlier part we have glows at Otaki, homogenous arcs at Christchurch and nearby localities, rayed arcs at Milton (south of Dunedin), and a corona at Campbell Island. Again at 23^h glows are reported from Wellington and Nelson, intensive rayed arcs reported from all the lower half of the South Island, and again a corona at Campbell Island.

No satisfactory method can be suggested at the moment for including New Zealand, Australian, Tasmanian, and Campbell Island observations for the determination of an index-figure. It therefore seems necessary at the moment to treat each locality separately.

The proposed method for dealing with New Zealand observations as a whole, is to treat them in such a manner that they will be reduced to a point of observation situated along the geomagnetic meridian half way between the geomagnetic positions of Dunedin and Invercargill. From the reports received a number of parallel lines are drawn for each station, to give the period of observation for each, in the same manner as the Timaru observation was treated above. The lines are arranged roughly with the northern stations near the top of the paper and the southern stations near the bottom. Along these lines are plotted the symbols as given above. When completed a bird's-eye view of all the reports is available. Where some observers have ceased observations we find others taking their place, and a fairly good check among all the reports is readily visible. An intensity-scale

is then drawn for the whole display, taking each phase as it comes and naturally using the most intense form as seen in the south of New Zealand. The ordinates of the curve are taken in accordance with the proposed intensity-scale. From the completed curve, readings are then taken for every six minutes or 0.1 hour, and thus are obtained: (1) An intensity-measure for every six minutes; (2) an auroral number for each hour, obtained by adding the intensity-measures for the whole hour; and (3) an auroral number for the display, obtained by adding the hourly auroral numbers. It is suggested that this produces a set of indices capable of being used in all kinds of ways by any investigator. The rate of change in any display is approximately obtained from the six-minute values, the hourly values can be used for studying the broader outlines of the display, and the number for the whole display allows individual displays to be compared rapidly.

Examples of results for some of the large displays in the early part of 1946 are given in Table 1 to illustrate the type of figures obtained. All times are given in New Zealand Standard Time (NZST). The sum in last rows of second last column is auroral number for whole display.

These examples are of sufficient variety to show the several points mentioned above. The hourly sums and the auroral number are rough integrations. With a sufficient number of data of this kind it is suggested that useful results may be obtained in several fields of auroral enquiry. The plotting of the hourly sums for the displays given will show immediately the relative importance of each. From a rough preliminary study it also seems

TABLE 1—*Results of large auroral displays, February to April, 1946*

Decimal of hour	Hours										Sum	la-Cour scale
	19	20	21	22	23	00	01	02	03	04		
Display of February 7-8, 1946												
0.1	..	3	3	3	4	13	3	8	3	..		
0.2	..	3	3	3	5	12	3	8	5	.		
0.3	..	3	3	3	5	11	8	8	7	..		
0.4	..	3	3	3	6	9	3	8	8	..		
0.5	..	3	3	3	7	8	3	8	..	..		
0.6	..	3	3	3	9	5	8	3	..	..		
0.7	..	3	3	3	10	3	3	3	..	..		
0.8	..	3	3	3	10	3	3	3	..	..		
0.9	..	3	3	3	12	3	3	3	..	..		
1.0	..	3	3	3	13	3	8	3	..			
Sums	..	30	30	30	81	70	45	55	23	..	364	3

Table 1—*Results of large auroral displays, February to April, 1946*—Continued

Decimal of hour	Hours										Sum	la-Cour scale
	19	20	21	22	23	00	01	02	03	04		
	Display of February 8, 1946											
0.1	..	..	3	3	8	3	3	..	..	..		
0.2	..	..	3	8	8	3	3	..	..	..		
0.3	..	..	3	8	8	3	3	..	..	..		
0.4	..	..	3	8	8	3	4	..	..	..		
0.5	..	..	3	8	8	3	5	..	..	..		
0.6	..	..	3	8	8	3	5	..	..	..		
0.7	..	..	3	8	8	3	3	..	..	..		
0.8	..	..	3	8	8	3	3	..	..	..		
0.9	..	..	3	8	8	3	3	..	..	..		
1.0	..	..	3	8	3	3	3	..	..	..		
Sums	..	..	30	75	75	30	35	..	..	..	245	2
	Display of March 24-25, 1946											
0.1	..	..	11	5	3	12	6	5	3	3		
0.2	..	..	12	5	3	12	6	5	3	3		
0.3	..	..	12	5	3	10	7	5	3	3		
0.4	..	...	8	5	3	9	6	5	3	3		
0.5	..	..	8	5	3	6	5	8	3	3		
0.6	..	..	11	5	3	5	5	5	3	..		
0.7	..	..	12	5	3	6	5	5	3	..		
0.8	..	..	11	4	3	6	5	5	3	..		
0.9	..	..	10	3	3	6	5	5	3	..		
1.0	..	..	7	3	12	6	5	3	3	..		
Sums	..	..	102	45	39	78	55	51	27	15	412	3
	Display of March 25-26, 1946											
0.1	..	9	10	5	9	12	5	7	5	5		
0.2	..	8	9	5	11	12	5	6	5	5		
0.3	5	8	8	5	13	12	5	5	5	5		
0.4	5	8	13	5	14	12	5	5	5	5		
0.5	5	8	14	5	15	12	5	10	5	5		
0.6	5	8	14	5	14	11	5	5	5	5		
0.7	5	5	11	5	14	5	5	5	10	10		
0.8	5	5	8	5	13	5	5	5	5	5		
0.9	5	5	6	5	12	5	5	5	5	5		
1.0	10	8	5	6	12	5	5	10	5	5		
Sums	45	72	98	51	127	91	50	63	55	55	707	4

TABLE 1—*Results of large auroral displays, February to April, 1946*—Concluded

Decimal of hour	Hours 19	20	21	22	23	00	01	02	03	04	Sum	la-Cour scale
					Display of March 28-29, 1946							
0.1	..	..	8	8	10	..	..	..	2	..		
0.2	..	..	8	8	10	..	..	..	2	..		
0.3	..	..	12	8	10	..	..	..	2	..		
0.4	..	..	11	8	5	..	..	..	2	..		
0.5	..	..	8	8	3	..	..	..	2	..		
0.6	..	..	8	8	3	..	..	..	2	..		
0.7	..	..	8	14	3	..	..	..	2	..		
0.8	..	..	8	15	3	..	..	..	2	..		
0.9	..	..	8	12	3	..	..	..	2	..		
1.0	..	..	8	10	3	..	..	..	2	..		
Sums	..	..	87	99	53	..	..	..	20	..	259	4
					Display of April 23-24, 1946							
0.1	..	11	7	9	14	11	12	12	3	6		
0.2	3	11	7	9	12	14	12	12	3	4		
0.3	3	10	7	10	10	14	12	12	3	3		
0.4	3	10	7	11	9	12	12	12	3	3		
0.5	3	9	7	12	10	12	12	14	3	3		
0.6	4	8	7	13	10	12	12	12	3	3		
0.7	7	8	7	14	10	12	12	12	3	3		
0.8	11	8	8	15	10	15	12	11	3	..		
0.9	12	7	8	15	9	13	12	6	4	..		
1.0	11	7	8	14	9	13	12	3	8	..		
Sums	57	89	73	122	103	128	120	106	36	25	859	4

that in the case of long-enduring displays the same general features are repeated each night with a shift in phase of one hour earlier.

Consideration of complete auroral activity—Most auroral work has of necessity been considered from the point of view of single stations, and the observers and many research workers think of the auroral display in terms of a two-dimensional picture rather than a three-dimensional one varying continually with time. It is true that the monumental work of Störmer in Norway has given us three-dimensional pictures of certain auroral forms, but there seems to be a lack at the present time of the complete picture of what is happening right from the regions of the auroral zone to the lowest geomagnetic latitude at which the display is visible during an intense display.

At this point it is worth considering exactly what is meant by the auroral zone. It is perhaps correct to say that in the first place, being derived from auroral frequencies along a geomagnetic meridian, it is a statistical result; but it has a physical interpretation in so far as we may say that it is that region on the Earth at which auroras will always be visible in the zenith during undisturbed periods. At disturbed periods, which we feel sure are produced by sunspot-activity of some kind, this zone moves, in the case of the Aurora Australis, northwards. The amount by which it moves northwards would apparently be some measure of the degree of the total disturbance. To make some index capable of measuring this disturbance, however, does not at present seem very easy. If an aurora is seen at Auckland for example, it would be highly desirable to have a complete picture of all auroral forms for the period of the display, right from Auckland to the auroral zone itself in Antarctica. The amazing pictures of Mawson show rayed arcs one after another receding northwards into the distance, and it would seem that in the case of large displays a large volume of the Earth's atmosphere contains the auroral discharge right from the auroral zone to the northernmost latitudes. This is supported exceedingly well by the observations made so far at Campbell Island, and is one of the many reasons for the importance of this auroral station. Displays have been observed there on both the north and south horizons simultaneously. This occurred among other times on April 23, 1946, and March 15, 1947. To enable any reliable method to be evolved, so as to give an evaluation of the whole auroral field at any instant, it will be necessary to study carefully data from New Zealand, Campbell Island, and Tasmania. It would be invaluable if at the present time a station could be established in Antarctica, so that observations could be obtained almost along a geomagnetic meridian for a considerable distance.

It is now well established that the Aurora Borealis and the Aurora Australis are not isolated or separate phenomena. There are many cases on record where displays of the Aurora Australis have been terminated by daylight, and the auroral activity has been maintained by the appearance of the Aurora Borealis where night is commencing. Moreover both have been observed simultaneously from the opposite hemispheres. The Aurora Polaris is therefore something of a complete planetary phenomenon, and an absolutely complete index of auroral activity should include the phenomena of both poles. This calls for a high degree of national and international cooperation for which at the present time New Zealand is not properly equipped.

Summary—The assumption is made that at any instant, the intensity of an auroral display is directly proportional to the auroral form in evidence. A scheme is suggested for allotting an index-number to each of the regular auroral forms. Where more than one auroral form is present at any instant, the intensity is taken as the sum of the indices for the various forms.

In dealing with New Zealand observations, reductions are made to a hypothetical station midway between Dunedin and Invercargill. Until such time as more is known concerning the distribution of auroral activity throughout the expanded auroral zone during large disturbances, the observations of Campbell Island, Tasmania, and Australia will be treated separately.

From the resulting analysis of observations, values of intensity for every six minutes are deduced. An hourly summation of the six-minute values gives an hourly auroral number, and the sum of the hourly numbers gives an auroral number for the whole display. This takes into account auroral intensities and duration. It still suffers at the moment, however, from interference by daylight, cloud, and the absolute dependence upon voluntary observers.

The preliminary investigations outlined above indicate that such numbers may give a truer evaluation of a display than previous methods.

The desirability of extending this investigation with a view to obtaining some index of auroral activity as a whole is briefly discussed.

Acknowledgements—The writer wishes to acknowledge with thanks the valuable discussions with J. H. Sorensen, who has had many years of experience in auroral observation, and who assisted in determining the index-values for the auroral forms. The writer also feels indebted to the late M. Geddes, whose pioneering work in this field has had a large influence upon the writer's knowledge of the subject.

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Carter Observatory,
Wellington, W. 1, New Zealand, June 10, 1947

NOTES

(See also pages 477, 492, 496, and 534)

(46) *Observatories in south polar regions*—We have learned from a letter from J. M. Rayner, Chief Geophysicist of the Bureau of Mineral Resources, Victoria, Australia, that the Bureau, during the next four years will be operating two observatories in Antarctica and on the Sub-Antarctic Islands.

(47) *Geophysical Society in China*—Dr. C. Y. Fu advises the JOURNAL (October, 1947) of the recent organization of a Geophysical Society in China. The new society will publish a semi-annual Journal to begin early in 1948, and will include the magnetic data measured in China.

(48) *Temporary magnetic observatory in Sweden*—From the annual report of the Magnetic Observatory at Lovö (Stockholm) for the year 1942 (published in 1944), it is noted that a temporary observatory was established at Lycksele, latitude 64° 36′.0 north and longitude 18° 40′.7 east, which functioned during the time of field-observations. The necessary instruments (la Cour type) for this station were furnished through the cooperation of the Royal Academy of Sciences (Kungl. Vetenskapsakademien).

(49) *Departments on general geophysics and on terrestrial magnetism, Institute of Meteorology, Chinese National Academy*—Director Jeou-jang Jaw of the Institute of Meteorology, Academia Sinica (Pei-Chi-Ko, Nanking, China) has recently, according to Dr. C. Y. Fu of the Institute, established two new departments, namely, on general geophysics and on terrestrial magnetism. Fortunately the library of the Institute escaped the damage of war and, except for a few missing numbers, has most of the important literature published before 1939 on meteorology, geophysics, and geomagnetism. The library of the Institute is perhaps the best in China so far as meteorological and geophysical literature are concerned. The Institute would appreciate receiving scientific publications issued since 1939.

(50) *Publication of geophysical abstracts*—The United States Geological Survey has resumed publication of the *Geophysical Abstracts* after a four-year interval, during which they were issued by the United States Bureau of Mines. The *Geophysical Abstracts* are published quarterly as an aid to those engaged in geophysical research and exploration. The Bulletin covers world literature on geophysics contained in periodicals, books, and patents. It deals with exploration by gravitational, magnetic, seismic, electrical, radioactive, geothermal, and geochemical methods and with underlying geophysical theory and related subjects. Copies may be purchased singly or by annual subscription from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. For subscription, the Superintendent of Documents will accept a deposit of $5.00 in payment for subsequent issues. When this fund is near depletion the subscriber will be notified. The deposit may also be used to cover purchase of any other publication from the Superintendent of Documents.

NOTES ON THE AURORA AUSTRALIS*

By I. L. Thomsen

Before 1933 very little was known concerning the appearance of the Aurora Australis as seen from New Zealand, except from odd newspaper reports and the casual remarks passed by residents of the southern half of the South Island. Certainly very little, if anything, was ever published in scientific transactions. The general feeling of the scientific world at large, was that if one wished to study aurora in the Southern Hemisphere it was necessary to make a trip to the Antarctic. Up to the time of the Byrd Antarctic Expedition of 1929, most of our knowledge of the Aurora Australis had been obtained from the printed reports of Antarctic expeditions, commencing with Cook in 1773. One notable exception, however, were the records of aurora obtained by Neumayer at Melbourne during 1859 to 1862.

About 1930 the writer commenced what was called the Aurora and Zodiacal Light Section of the New Zealand Astronomical Society, but this had been transferred to the late M. Geddes, who was then in the South Island, by 1933. Geddes proved to be the most enthusiastic, energetic, and able observer that could have undertaken such work, and it may be said that he was the pioneer of our New Zealand knowledge of the Aurora Australis. He continued this work up to the time of his appointment as Director of the Carter Observatory in 1939 in an amateur capacity, and then made auroral work one of the activities of the Observatory.

It is sometimes suggested that observations of aurora from New Zealand have little worth compared with Antarctic observations, but it is hoped that the contents of this note will show how usefully such work can supplement Antarctic data. If we indicate on an idealised curve of the eleven-year sunspot-cycle, the positions of the various Antarctic expeditions from the time of Cook onwards, as summarised by White [see 1 of "References" at end of paper], it is rather surprising how they cluster round the time of minimum sunspot-activity, commencing one and one-half years after maximum. Our knowledge of the Aurora Australis as seen from the Antarctic, close to the auroral zone itself, is therefore confined to the lower parts of the sunspot-curve. Moreover a good many of these expeditions were for only short periods, and the observers working under most difficult conditions, have not always given us just the data we require. Had it been possible to have had an Antarctic expedition wintering there this year, near the time of solar maximum, it would have been unique. It would seem that even next year would not be too late. The observations from New

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Zealand have several advantages. Quite apart from any other characteristics, the Carter Observatory now has continuous records of aurora seen in New Zealand for nearly one and one-half sunspot-cycles. Much of this data has been published in summary form up to 1939 by Geddes [2, 3], but there is now a wealth of material awaiting re-discussion from the point of view of frequencies. Each New Zealand aurora recorded has some significance for the polar auroral activity as a whole, because in each case it indicates a

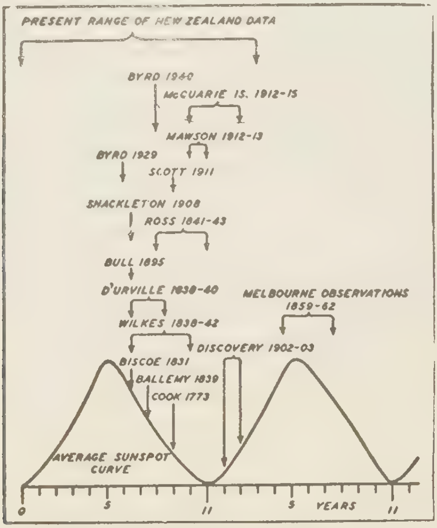

FIG. 1—DISTRIBUTION OF ANTARCTIC EXPEDITIONS ON SUNSPOT-CURVE

northward advance of the zone, and thus an increase above what might be termed "quiet" auroral periods. The large dispersal of voluntary observers must tend to reduce the effect of cloudy skies when taken over a long period of time. The facts that New Zealand and Tasmania are the closest inhabited land-masses to the auroral zone, and that displays can be observed from them, render it obligatory that attention should be given to auroral phenomena. The establishment of an auroral station at Campbell Island has been a most important step in linking New Zealand observations with those made in sub-Antarctic regions. An intensive winter's work, with observations from Antarctica, Campbell Island, New Zealand, and Tasmania should provide data of fundamental importance in describing auroral phenomena along a geomagnetic meridian from the auroral zone to fairly low geomagnetic latitudes.

Auroral forms—It is now fairly well established that the same general auroral forms seen in the Northern Hemisphere, are to be seen in Southern-

Hemisphere displays; and during a display the same sequence appears. There is much evidence, some of it still awaiting investigation in the records now available, of the appearance of remarkable auroral forms as described by Störmer [4]. Homogenous arcs at high altitudes have been seen in New Zealand, and several times during the past few years at Campbell Island. There is no doubt that other remarkable forms have also been observed, but the reports still await analysis.

Future requirements on auroral forms necessitate the assistance of experienced, critical observers, in order to trace the development of forms and their more minute characteristics. The relationship of colour to form is a subject in which observers should be capable of making and recording the events in the greatest detail in such a way that at a later time some broad generalisations can be made. In such a favourable locality as Campbell Island, where several forms are visible on occasion at the same time, the relationship, if any, of the different forms should be investigated. The auroral forms visible at any given instant, and their approximate positions, from the auroral zone to the furthest north geomagnetic latitude, are matters of some interest in gaining a complete picture of auroral activity.

Although it may be impossible of achievement, it would be of some importance to the subject as a whole if an observer could be sent to the Northern Hemisphere for a year and in the succeeding year be stationed at Campbell Island, so that a more direct comparison of the two polar aurora could be made. This is suggested because of the many statements made by travelers to the effect that although the same forms may be apparent, the northern aurora have a quality lacking in the southern aurora.

Auroral heights—Although considerable information is now available, or on record, of auroral frequencies and forms, data are sadly lacking concerning auroral heights in the Southern Hemisphere. Some years ago Störmer kindly loaned to New Zealand two auroral cameras of the same type as used by himself in Norway, and these were used as much as possible by Geddes [5]. It has to be clearly appreciated that in carrying out this work, Geddes was working under great difficulties in his spare time, and his efforts are worthy of only the highest praise. The fact remains, however, that his work can only be considered as a preliminary trial in this field. The published results include measures of only 18 duplicate photographs, and it is upon this evidence that up to the present time auroral workers in New Zealand have taken it for granted that, in general, auroral heights for the Aurora Australis are of the same order as those for the Aurora Borealis. It must, however, be pointed out that if this were not so, in general, we could not account for certain aspects of auroral displays. However, the fact must be faced quite clearly, that we have no accurate knowledge of auroral heights in the Southern Hemisphere, which is remotely comparable with that in the Northern Hemisphere.

One of the most important future needs of auroral work in the Southern Hemisphere therefore is the commencement and maintenance of height-measurements. It has to be realised that such work is of a more exacting nature than just the general observation of aurora, and the reductions are both laborious and time consuming even with short-cut methods. The present policy of the writer with respect to this work is that if it cannot be done well, both as regards accuracy and multiplicity of observations, it would be best to leave it alone until such time as these requirements can be fulfilled. Other requirements are, a good base-line, reliable observers, inter-communication between observers, and the means of measuring and reducing the plates as soon as possible after the observations have been made in order that there is not an over-accumulation of unreduced material.

Some consideration has been given to base-lines, and it is suggested that at the moment, with only two cameras available, they should be located in New Zealand in the vicinities of Dunedin and Invercargill. Such locations should tend to give reasonably good parallaxes for both arcs and rays, as well as give a reasonable length of base-line. The location in New Zealand is recommended because of the fact that observations could be secured over a long period of time compared with short-term visits to the Antarctic. Some thought was given to the possible location of one camera at say Invercargill and the other at Campbell Island, but two difficulties seem to arise here. First, in the case of an aurora occurring between these two localities, the two stations would see perhaps different aspects of the display, and it may lead to uncertainties in the measuring process as to whether the same auroral point was being measured. Second, an aurora visible in the south at Campbell Island may not be visible at Invercargill. At the present time, it would also be possible to connect Campbell Island with the south of New Zealand if considered necessary, because of the fact that theodolite measures of aurora are made at Campbell Island, with an accuracy comparable to photographic work. The only difficulty is that of being sure that the same form was being measured. With care this should be possible in many cases, particularly for homogenous arcs.

If the base-line and observers are satisfactorily selected, and numerous observations become available, the reductions then become primarily the work for an observatory. The Carter Observatory is so completely lacking in staff that it could not guarantee at the present time that the reductions could be made. This is perhaps the prime factor which has so far delayed the putting into effect of a vigorous program of auroral height-measurement. It has often been suggested that parts of this work could be carried out by University honours students, but it is submitted that such results as would be obtained would of necessity be somewhat patchy and perhaps not take us any further than our present knowledge. The essence of the work at present would be continuity of observation and reduction over a reasonable

period of time. The writer submits that a reasonable period of time would mean at least one complete sunspot-cycle.

Geographic position of aurora and the auroral zone—Most of the determinations of the geographical positions of individual auroras have been deduced by Geddes [5, 6], by assuming heights for given forms, based on the Norwegian results. Even if such assumed heights are a little in error, the approximate location of most of the displays must be fairly reliable. His general results may be summarised as showing that most of the aurora seen from New Zealand are located over the Auckland and Campbell Islands, and on occasion may reach up as far north as Taranaki. In this result it must be remembered that his work was near and at the time of last sunspot-maximum.

This point must be emphasised when considering the determination of the auroral zone by White and Geddes [7]. In considering the Macquarie Island data they state:

> The observations at Macquarie Island (Mawson) indicate that the most frequent occurrences are from south to southwest with almost as many from south to southeast. . . . While there were a few zenith-auroras at Macquarie Island during the period of observation, the proportion was not great enough to suggest that this Observatory lies on the Zone. The Macquarie Island data are, however, in conflict with the observations of Geddes from the south of New Zealand. Many auroras have been observed by Geddes, who has also found that the majority are situated in the vicinity of the Auckland Islands.

A later determination of the southern auroral zone by Vestine [8] has shown little fundamental difference for that region plotted by White and Geddes. The apparent conflict between the observations of the Mawson Expedition and those of Geddes is due to the fact that Mawson's observations were made right at the time of sunspot-minimum and those of Geddes at the time of sunspot-maximum. This leads the writer to believe that there is a large expansion and contraction of the auroral zone as it were, in sympathy with the sunspot-cycle. This has also been suspected by Vestine, who suggests that such variations may be greater in the case of the southern auroral zone than the northern. It is also borne out very well by the fact that up to 1946 observations at Campbell Island, which were practically continuous from 1941, showed all displays confined to the southern horizon, except in the cases of coronas. In 1946 cases of rayed arcs appearing on the northern horizon are recorded as well as the case of a homogenous arc on the northern horizon on March 15, 1947. An analysis of the Campbell Island observations after the solar maximum may be able to reveal the gradual creeping up of the auroral zone from minimum to maximum solar activity. This is another instance of the importance of New Zealand observations and the still greater importance of the station at Campbell Island. It also shows that the discrepancy noted when dealing with the Macquarie Island data was

due neither to errors of observation by Geddes nor to Mawson, but was the direct effect of the solar cycle on the auroral zone.

In the same way that New Zealand observations may be utilised to some extent in the study of the behaviour of the auroral zone, Tasmanian observations by a group of enthusiasts there can also prove to be of great assistance in giving us a larger picture with respect to geomagnetic longitude.

Frequencies—At present quoted frequencies refer mainly to observations over the whole of New Zealand, and this has caused some confusion to overseas workers as is shown by Vestine, who takes a mean position in New Zealand near Wanganui. In actual fact most of the observations have previously been unconsciously reduced to the south of the South Island, and in recent years have been deliberately dealt with in this manner. The time is now ripe to make a thorough analysis of the records on hand, to obtain frequency-curves for New Zealand alone. Such a study would have interest from the point of view of the auroral zone also.

It may be noted, that the work commenced by Geddes, and now being continued, has shown us that auroral frequencies in New Zealand are much greater than was thought previously. Indeed, it may be stated as a generalisation that auroral frequency in the Southern Hemisphere is as great as that in the Northern.

Auroral data and geomagnetic coordinates—In studying the Aurora Australis as a whole, the writer has felt the need of expressing much data in relationship to the auroral zone. This zone is eccentrically placed with respect to geographic coordinates and in discussing the observations of say Antarctica, Campbell Island, New Zealand, Tasmania, and Australia the results have little physical meaning unless considered in relation to the auroral zone. Although our present knowledge of the auroral zone can perhaps still be improved, it is probably not far from the real truth. An examination of the chart by Vestine [8] shows that the auroral pole is not far from the magnetic-axis pole, and it would therefore be sufficient for most purposes to consider auroral phenomena in relationship to the geomagnetic coordinates.

An early piece of work, which it is hoped will be undertaken at the Carter Observatory, is to compute a network of geomagnetic elements, which can be used in both tabular or chart form for rapid use by investigators. Future work should also consider the conjoint use of GMT, local time, and geomagnetic time as used by Vegard. GMT is useful when considering auroral events from a world point of view, local time for its relationship to the solar day, and geomagnetic time for its relationship with the geomagnetic rather than the geographic coordinates.

Auroral spectroscopy—So far as is known, absolutely no work has been carried out on auroral spectroscopy in the Southern Hemisphere. The need for such work ranks in importance with the need of auroral height-determi-

nations. From observations with a small pocket spectroscope by B. E. Stonehouse of Lower Hutt, however, we know that some of the principal auroral lines must be of fairly high intensity during even moderate displays as seen from the Wellington Area. During the display of September 22, 1946, he observed three lines, one each in the blue, green, and red, which the writer has taken to be the lines 4277Å, 5577Å, and 6300Å.

The preliminary need is to make trials with such equipment as might already exist, and adapted to the purpose, to gain some idea of the possibilities. After this a spectroscopic program may be divided into two main branches; that of using the variation of line-intensity with auroral activity, and the more detailed spectroscopy designed for the purpose of obtaining knowledge of the atomic processes involved.

An indication of the uses to which variations of line-intensity may be put, for both diurnal, seasonal, and solar-cycle variations, may be gained from the valuable paper by Currie and Edwards [9]. In connection with such work attention should be directed, however, to the possibly greater uses of lines near or in the infrared. Baade, at Mt. Wilson Observatory [10], has drawn attention to the troublesome variations in intensity of the red (OI) doublet at 6300Å and 6364Å, when using plates and filters giving maximum intensities in the range 6300 to 6700Å for the photography of extra-galactic nebulae. He remarks that this doublet (*a*) displays erratic intensity-changes from night to night and (*b*) even on the same night, (*c*) may surpass that of the line 5577Å in intensity by a factor of two or more at the time of sunspot-maximum. This is remarkable when we notice that in Vegard's table of auroral lines and bands, 6300Å is assigned an intensity of only 28 per cent that of 5577Å. It is also worthy of notice that the Solar Physics Committee of the Cambridge University is investigating a newly discovered strong radiation near 10,400Å. However, good results would probably be available using the more normal wave-lengths. If it were possible to build a relatively cheap model spectrograph making automatic exposures during the night hours, a half a dozen placed strategically from Campbell Island up through New Zealand would be expected to give results of considerable interest.

The more detailed work in spectroscopy requires, as an adjunct, accurate height-determinations. If for example the spectroscope is directed towards a certain part of a ray, it is of some importance to know the exact altitude of that region above the Earth's surface. This can only be done in conjunction with simultaneous height-determination by photographic or theodolite means at two ends of a base-line with intercommunication, or having perfect confidence, from a large number of height-determinations, that an altitude can be safely assumed. Calibration-spectra would also be required on the same plate.

Photometry of detailed forms—Needless to say, exact photometric work

is non-existent in the Southern Hemisphere, but here again it would have little physical worth unless supplemented by height-determinations.

Present organisation of auroral work—It may be said that the immediate work being done at present is in connection with recording the occurrences and intensities of aurora. For this purpose voluntary observers—to the number of 300 are on the books of the Carter Observatory at present—report when they see an aurora, and give such details and information as their skill and time will allow. Valuable reports are also received from the Tasmanian Astronomical Society and from a few enthusiastic observers in Australia. In addition to this are of course the invaluable reports and observations from Campbell Island. The Magnetic Observatory at Christchurch is at present giving the fullest cooperation and assistance in dealing in detail with the Campbell Island observations, and in organising a special little band of observers in Canterbury. At present the two auroral cameras are in the care of Messrs. Berry and Matheson at Dunedin and Otautau, respectively, and are used to take photographs during intense displays. As such photographs are only useful for the purpose of recording auroral forms, and determining positions from assumed heights, until such time as a base-line can be properly organised, they are at present being filed only for reference purposes.

The future of auroral work—At the present time it would seem that auroral work must rank among the highest of the Cinderella sciences in New Zealand, with very little future unless more support is received. The outstanding need at the moment is the appointment of a worker with the right temperament and an interest in such work to spend his full time in organising even better the present reporting system and the collection of general data including photographic material. It must surely be agreed that auroral work is of immense interest to the geophysicist and radio engineer in general and the geomagnetician in particular. All our present theories concerning solar and terrestrial relationships are based on wave- and particle-radiation from the Sun. If we follow through the theoretical work of Birkeland, Störmer, Chapman, Vegard, and others, we are led to the conclusion that in the display of an aurora we are seeing the visible results of the bombardment in the upper atmosphere of particles from the Sun—in just those regions in which radio phenomena and geomagnetic effects have their being or birth. To study more fully the Aurora Australis is not only of pure scientific interest but also of practical importance.

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CARTER OBSERVATORY,
Wellington, W. 1, New Zealand, June 10, 1947

NOTES

(See also pages 468, 492, 496, and 534)

(51) *Monthly Bulletin of Information, International Council of Scientific Unions*—Issue No. 1 for September, 1947, of a *Monthly Bulletin of Information* by the International Council of Scientific Unions has appeared in mimeographed form. This *Bulletin* includes notes of interest to the activities of the Council and of its Unions. Of particular value in the first issue is a Calendar of meetings or assemblies from October, 1947, to September, 1951, and a detailed list of countries adhering to UN, UNESCO, ICSU, and to the several Unions of ICSU. Information of the kind to be given will be of great value in international scientific relations. The Liaison Officer for ICSU and UNESCO is Dr. A. Establier, whose address is UNESCO House, 19 rue Kléber, Paris 16, France; he is editor of the new *Bulletin*.

(52) *Magnetic disturbances*—The following notes on magnetic disturbances are reported in United States *Hydrographic Bulletin* (No. 3028 of September 20, 1947):

American SS *Richard S. Ewell* reports at $09^h\ 20^m$ GCT, July 24, 1947, a disturbance which pulled the magnetic compass 10° to left while on true course 263°; the compass returned to the course in three minutes.

American SS *Cornelius Gilliam* reports from $08^h\ 45^m$ to $09^h\ 15^m$ GCT, July 29, 1947, while passing north of Rockall, through latitude 58° 39′

north, longitude 14° 40′ west, the compass was deflected 10° from normal and during this period the ship's radio failed to operate.

American SS *Dartmouth* reports at 12^h 00^m GCT, August 8, 1947, in latitude 3° 27′ south, longitude 37° 07′ west, the ship's magnetic compass changed 3° to the left. The ship was steered by gyro-compass, course 301°; magnetic compasses, both standard and steering, 320°, and checked with gyro at 11^h 00^m GCT. At 12^h 00^m GCT, the magnetic compasses checked 323°. At 21^h 00^m GCT, August 8, 1947, in latitude 2° 09′ south, longitude 39° 19′ west, both magnetic compasses came back to normal.

United States *Hydrographic Bulletin* (No. 3034, November 1, 1947) contains the following report from Captain C. J. Van Trier of the American SS *Paine Wingate:* En route from San Francisco to the Panama Canal on September 22, 1947, at 15^h 00^m (zone plus 7 time), in latitude 20° 34′.5 north and longitude 108° 04′ west, there was a magnetic disturbance which lasted for about 3½ hours over a distance of about 42 miles to latitude 20° 08′.5 north and longitude 107° 30′ west. Both magnetic compasses changed headings rapidly and simultaneously as much as 20° then slowly settled down to their former headings. This action was repeated four times during the period while the vessel continued on the course of 129° (gyro). A speed of 12 knots was maintained. Wind was northwest of force 2 with barometer at 29.84 inches and moderate northwest sea.

(53) *Aurora Borealis, September 13, 1947*—The United States *Hydrographic Bulletin* (No. 3030 of October 14, 1947) contains a report by the Second Officer of the American SS *Great Meadows* as follows: "In latitude 39° 00′ north, longitude 69° 40′ west, while on course 356° (gyro), a display of Aurora Borealis was observed extending between the bearings 310° and 20°. This display was observed on September 13, 1947, from 02^h 00^m to 09^h 00^m GCT. It was continuous throughout this period with occasional flashes of brilliance. The wind was northwest, force 2, with slight westerly sea and barometer reading 30.00 inches."

(54) *Awards in 1947 of the Charles Chree Medal and Prize and of the Duddell Medal of The Physical Society*—The fourth biennial award in 1947 of the Charles Chree Medal and Prize has been made to Sir Edward Appleton in recognition of his pioneer investigations on the ionosphere by radio methods.

The 24th award in 1947 of the Society's Duddell Medal has been made to Dr. R. J. van de Graaf of the Massachusetts Institute of Technology in recognition of the invention and development of his high-voltage generator.

SOME EXPERIMENTAL RESULTS OBTAINED BY IONOSPHERIC INVESTIGATIONS IN SWEDEN DURING THE TOTAL SOLAR ECLIPSE OF JULY 9, 1945

By Sven Gejer and Per Åkerlind

Summary—Determinations of critical frequencies and virtual height made by the Swedish Board of Telegraphs are described and also other measurements made in Sweden during the eclipse.

Definite effects on the critical frequencies for the different layers were established by means of multifrequency recordings made at Östersund and Enköping. Thus the decrease in E-layer electronic density from the assumed undisturbed value was about 57 per cent. For the $F1$-layer the corresponding decrease was 63 per cent and for the $F2$-layer approximately 33 per cent.

Signal-strength measurements on the short-wave broadcast station WGEO, 15330 kc/s, showed a definite decrease of about 95 per cent from the assumed undisturbed value during the eclipse. Field-strength measurements on medium-wave broadcast stations on 392 kc/s and 1131 kc/s showed no influence from the eclipse.

(1) *Introduction*—The program of the ionospheric measurements and investigations during the eclipse was outlined by the Swedish National Committee of the International Scientific Radio Union in cooperation with the institutions interested. The main results from the measurements were collected by the Committee and communicated by Professor O. E. H. Rydbeck to the Eighth General Assembly of the International Scientific Radio Union in Paris, October, 1946 [see 1 of "References" at end of paper]. In the present paper mainly the measurements made by the Swedish Board of Telegraphs are described, but results from other measurements in Sweden are also mentioned.

(2) *Locations of measuring stations*—The locations of the different ionospheric and measuring stations are shown on Figure 1. Multifrequency recordings were made by the Board of Telegraphs at Östersund (A in Fig. 1) and at Enköping (D in Fig. 1), by the Chalmers University of Technology under direction of Professor O. E. H. Rydbeck at Sörmjöle (C in Fig. 1) near Umeå [1] and by W. Stoffregen of the Institute for High Tension Research, University of Uppsala (Director of the Institute, Professor H. Norinder) at Hörnsjö near Umeå (B in Fig. 1) [2]. The Östersund station was just below the central line of totality at 270-km height while the Sörmjöle and Hörnsjö stations were just below the central line for totality at 100-km height. On Figure 1, the Tromsö station is also indicated. Measurements were made there by Professor L. Harang [3]. Positions, magnitude of eclipse, times of the first and last contact, as well as the time of the greatest eclipse, are given in Table 1; the times are given

for the Earth's surface—for the ionospheric layers the eclipse is a little later. Thus the greatest eclipse comes about 1.5 minutes later at 300-km altitude. The data of the eclipse and of the ionospheric central lines in Figure 1 are taken from calculations made by H. O. Grönstrand [4].

FIG. 1—IONOSPHERIC STATIONS, NORWAY, SWEDEN, FINLAND, AND DENMARK, SOLAR ECLIPSE, JULY 9, 1945

(3) *Apparatus used*—The multifrequency-recording apparatus used by the Board of Telegraphs at Östersund and Enköping were supplied by the Institute for High Tension Research, University of Uppsala. Both equip-

TABLE 1—*Details of eclipse for the various stations*

Station	Position	Magnitude of greatest eclipse	GMT for		
			First contact	Greatest eclipse	Last contact
	°	*pct*	*h m*	*h m*	*h m*
Sörmjöle	63.7 N 20.1 E	99	12 52	14 02	15 08
Hörnsjö	63.8 N 19.5 E	99	12 52	14 01	15 08
Östersund	63.2 N 14.6 E	95	12 48	13 59	15 07
Tromsö	69.7 N 19.0 E	93	12 45	13 52	14 57
Enköping	59.6 N 17.1 E	89	12 55	14 07	15 14

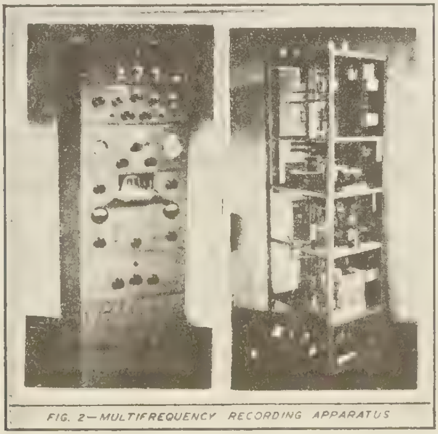

FIG. 2—MULTIFREQUENCY RECORDING APPARATUS

ments had been designed at that Institute by W. Stoffregen and constructed under his direction. The apparatus used at Östersund was fully automatic. The complete equipment, consisting of transmitter, receiver, and recording equipment, was housed in the same cabinet (Fig. 2) showing exteriors of the apparatus. Figure 3*A* shows sample records taken on the day of the eclipse. The equipment used at Enköping was semi-automatic, the transmitter and receiver being placed at some hundred meters' distance from each other; sample records taken by this apparatus on the day of the eclipse are shown in Figure 3*B*.

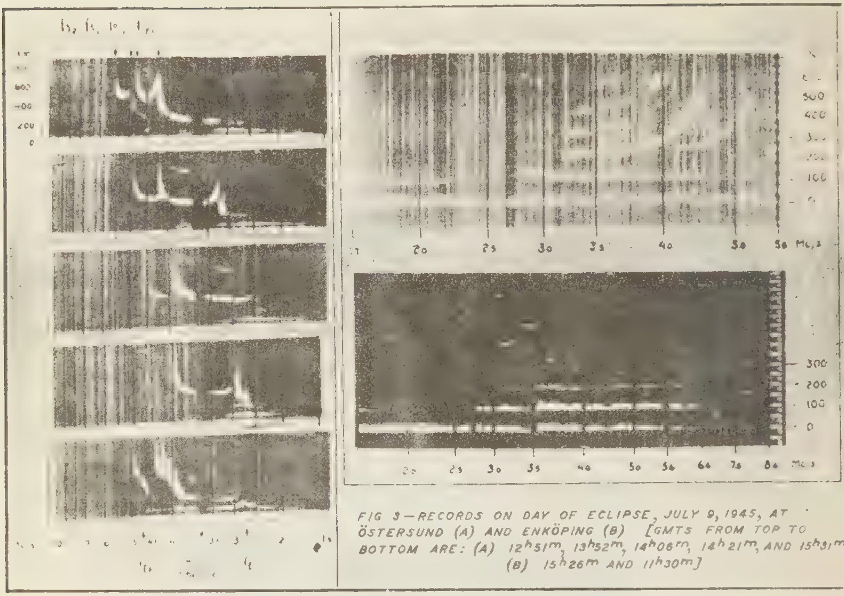

FIG 3—RECORDS ON DAY OF ECLIPSE, JULY 9, 1945, AT ÖSTERSUND (A) AND ENKÖPING (B) [GMTS FROM TOP TO BOTTOM ARE: (A) 12^h51^m, 13^h52^m, 14^h06^m, 14^h21^m, AND 15^h31^m (B) 15^h26^m AND 11^h30^m]

(4) *Results obtained by multifrequency recordings*—At Östersund recordings were made during the time from June 9 to July 15, 1945. More than 400 sweep-frequency recordings were made during this time. At Enköping about 250 sweep-frequency diagrams were recorded during June 21 to July 12, 1945.

The critical frequencies for *E*-, *F*1-, and *F*2-layers for July 6 to 12 are shown in Figures 4 to 6. The values at Östersund are indicated by crosses and dotted lines while those at Enköping are indicated by small circles. On some days strong sporadic *E*-layers made measurements of the critical frequencies for the normal layers impossible. At Enköping this happened for instance between 11^h 00^m and 12^h 15^m GMT on July 9, 1945. Figure 3*B* reproduces a record taken at 11^h 30^m GMT showing multiple reflections from a strong sporadic *E*-layer, this layer completely preventing penetration to the higher layer. At Östersund the sporadic *E*-layers were not strong enough to prevent reflections from the normal layers.

On July 6 quite a strong magnetic storm appeared as will also be seen from the signal-strength measurements on a USA short-wave broadcast station reported below. At Östersund the absorption was very strong on this particular day and no echoes at all were recorded before 13^h 30^m GMT. At Enköping, however, echoes were observed as normally. On the following days, from July 7 to 12, the conditions seemed to be quite normal except on July 9, when the effect of the eclipse was definitely observed.

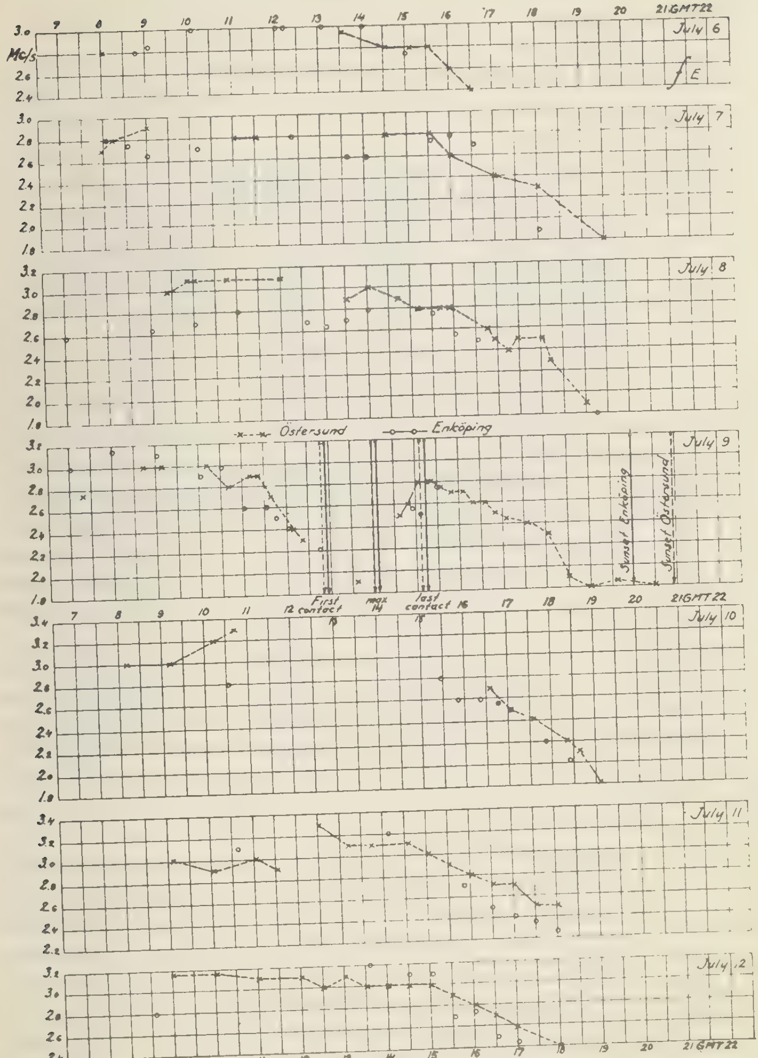

FIG. 4—CRITICAL FREQUENCIES, E-LAYER AT ÖSTERSUND AND ENKÖPING, JULY 6-12, 1945

Table 2 includes values of critical frequencies at Östersund at $14^h\ 00^m$ GMT for the days July 6 to 12, 1945. For July 9 the undisturbed value at $14^h\ 00^m$ GMT has been estimated and this value as well as the minimum value observed during the eclipse are tabulated in the Table.

TABLE 2—*Mean values of critical frequencies at 14^h00^m GMT at Östersund for July 6-12, 1945*

Layer	July, 1945			July 9, 1945		July, 1945		
	6	7	8	Estimated undisturbed value	Observed min. value	10	11	12
	Mc/s	*Mc/s*	*Mc/s*	*Mc/s*	*Mc/s*	*Mc/s*	*Mc/s*	*Mc/s*
E	2.9	2.8	3.0	2.9	1.9	3.0	3.1	3.0
*F*1	3.9	4.2	4.15	4.2	2.55	4.3	4.3	4.4
*F*2	4.4	4.8	4.6	4.7	3.85	5.1	5.2	5.4

For the *E*-layer it was not always possible to determine exactly the critical frequency from the records. From the values at Östersund it appears that the *E* critical frequency decreased from the estimated undisturbed value 2.9 Mc/s to about 1.9 Mc/s or by about 35 per cent, corresponding to a decrease in electronic density of 57 per cent. From the diagram in Figure 4 it appears that the decrease in critical frequency began about 1½ hours before the first contact. The same observation was made at Enköping.

For the *F*1-layer the critical frequency at Östersund decreased from the estimated undisturbed value 4.2 Mc/s to the minimum value 2.55 Mc/s, or by about 39 per cent, corresponding to a decrease in electronic density of 63 per cent. The minimum at Östersund occurred about 12 minutes after the time of the greatest eclipse. The decrease and increase in critical frequency seemed to be quite symmetrical around the minimum as will be seen from Figure 5.

Also for the *F*2-layer a definite decrease in critical frequency was observed during the eclipse. As seen from the curves in Figure 6 the *F*2 critical frequency has a tendency for a minimum at about $15^h\ 00^m$ to $16^h\ 00^m$ GMT. On the day of the eclipse the critical frequency decreased from an estimated undisturbed value of about 4.7 Mc/s to the minimum value of 3.85 Mc/s, or by about 18 per cent, corresponding to a decrease in electronic density of 33 per cent. No definite influence from a corpuscular eclipse could be seen (Fig. 6). In Table 3 the decrease in electronic density from estimated undisturbed values have been noted for the several measuring stations.

(5) *Signal-strength measurements*—At Hörby and Enköping the signal strength from the short-wave broadcast station South Schenectady, WGEO 15,330 kc/s, was recorded. The measuring equipments were identical in both places and consisted of a receiver with attached direct-current amplifier

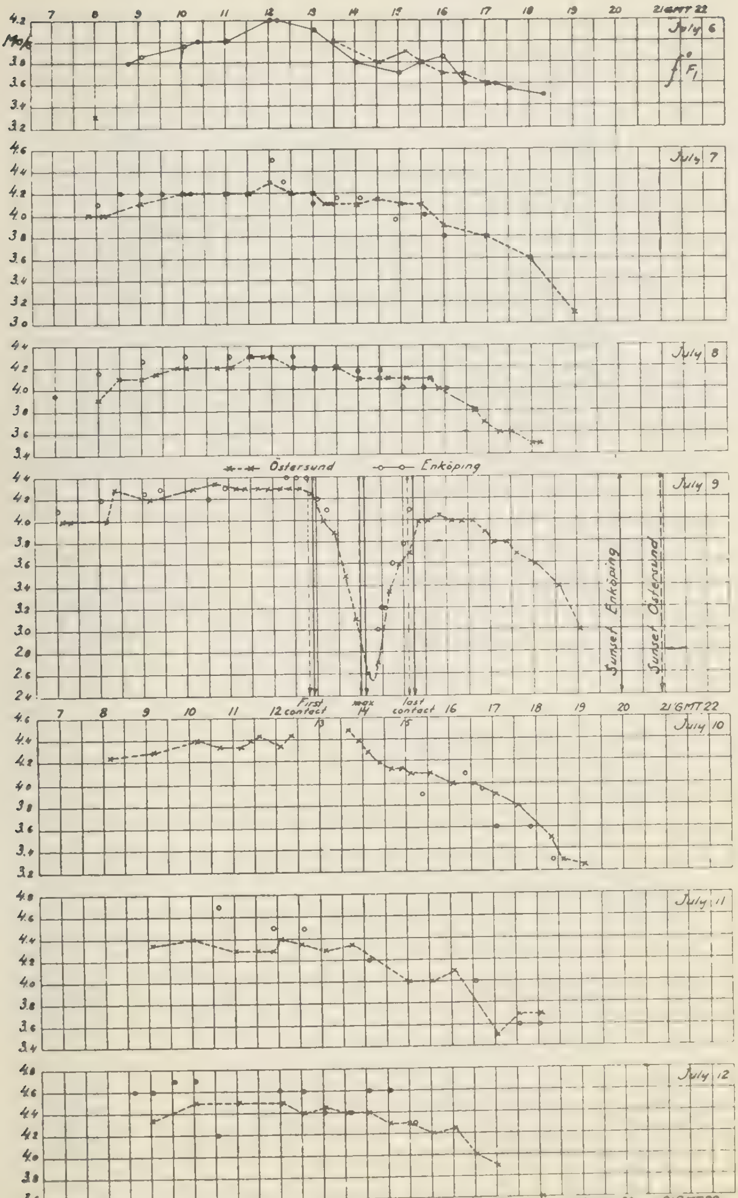

FIG. 5—CRITICAL FREQUENCIES, F1-LAYER AT ÖSTERSUND AND ENKÖPING, JULY 6-12, 1945

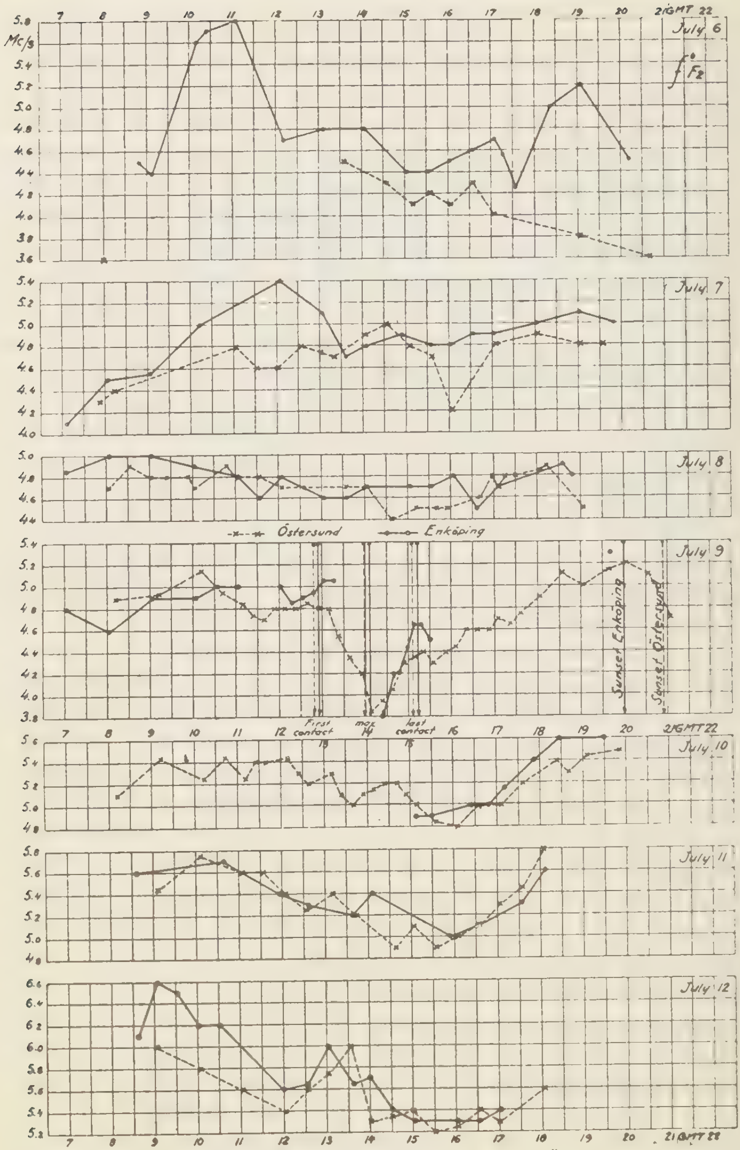

FIG. 6—CRITICAL FREQUENCIES, F2-LAYER AT ÖSTERSUND AND ENKÖPING, JULY 6-12 1945

TABLE 3—*Decrease in electronic density from estimated undisturbed values during the eclipse*

Station	Magnitude of eclipse	Decrease for		
		E	*F*1	*F*2
	pct	*pct*	*pct*	*pct*
Sörmjöle	99	58	59	21
Hörnsjö	99	36	68	15
Östersund	95	57	63	33
Tromsö	92	49	57	19

and ink recording mA-meter. The amplifier was connected across a resistor in the AVC-circuit. The receiver was connected to a rhombic antenna directed towards New York with a side length of 91.5 m, a height of 22 m, and an apex-angle of 37°. The receiver input was calibrated by means of a

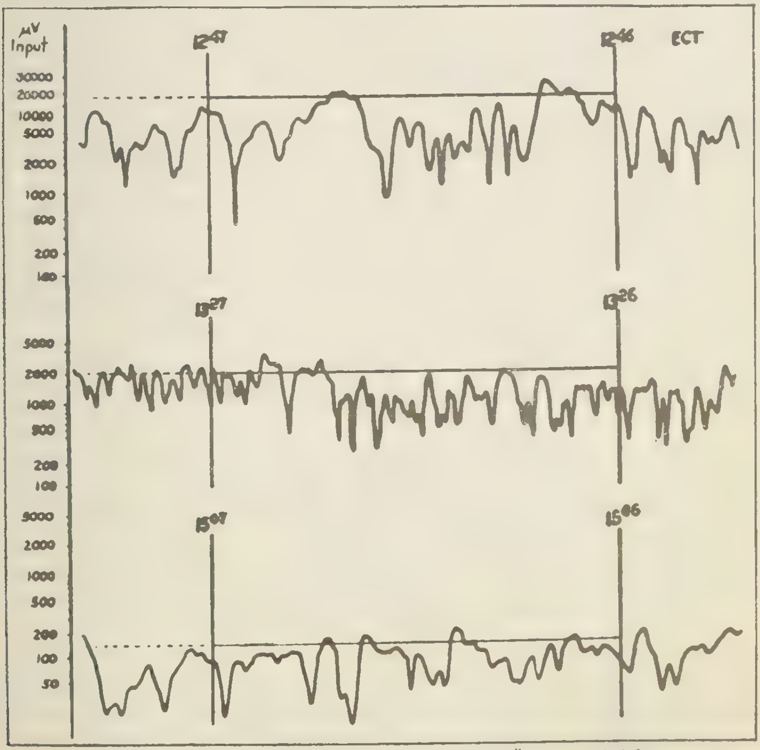

FIG. 7—SAMPLES OF SIGNAL-STRENGTH RECORD AT ENKÖPING, JULY 9, 1945

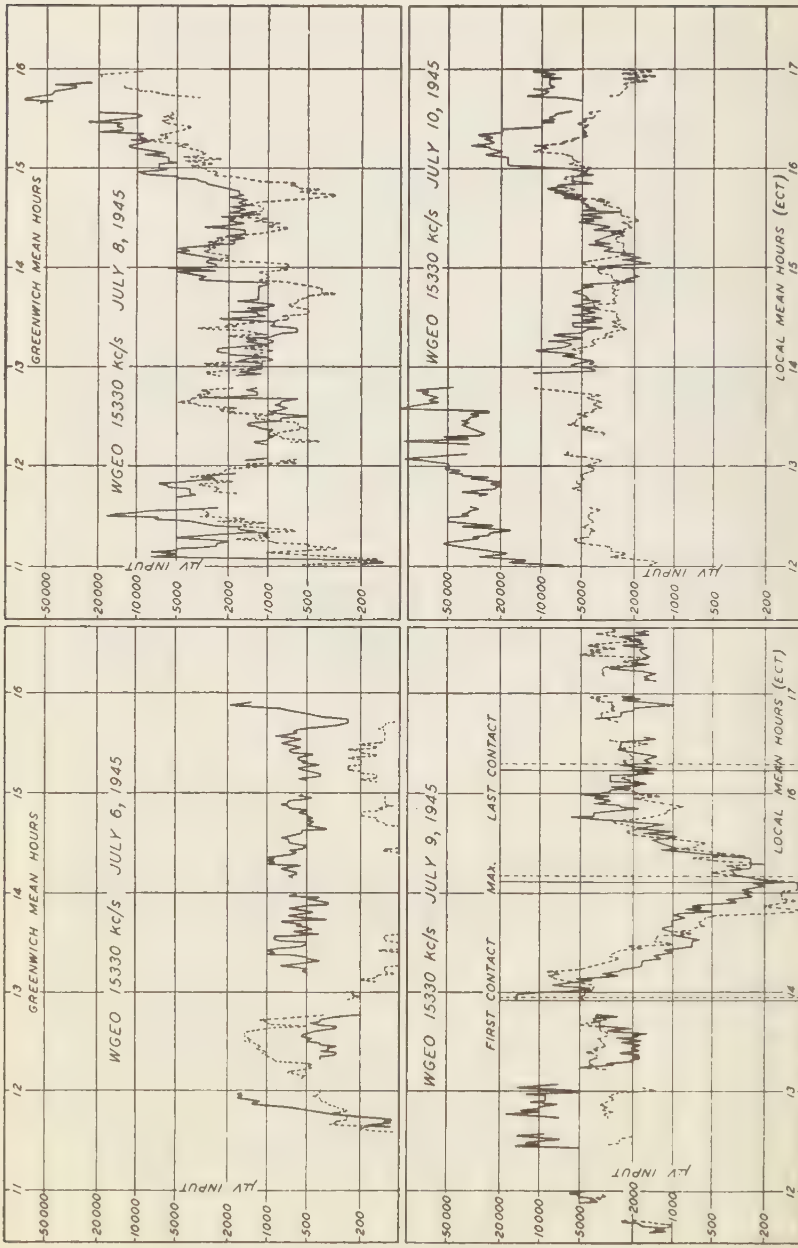

FIG. 8—SAMPLES OF SIGNAL-STRENGTH RECORD AT ENKÖPING (FULL LINES) AND HÖRBY (DOTTED LINES) JULY 6, 8, 9, 10, 1945

standard-signal generator and the whole equipment was connected to a mains stabilizer. The paper speed was about 100 mm per minute or about 1.7 mm per sec. Figure 7 shows samples of records taken at Enköping on July 9 at $11^h\ 46^m$, $12^h\ 26^m$, and $14^h\ 06^m$ GMT. From the original paper records quasi-maxima have been calculated for every minute, that is, the value reached during ten per cent of the time (one minute). Graphs showing quasi-maxima for July 6, 8, 9, and 10 are shown in Figure 8. The values obtained at Hörby are indicated by dotted lines and those obtained at Enköping by full lines. As mentioned before, a magnetic storm appeared on July 6 and the values at Enköping as well as those at Hörby were very low. On the following days the conditions were normal but on July 9 a definite decrease in signal strength was observed during the eclipse both at Enköping and Hörby. The signal strength decreased from values of about 4000 to 5000 μV to about 100–200 μV. At Enköping the minimum signal strength occurred at the time of the maximum eclipse, but at Hörby the minimum signal strength seemed to be about ten minutes before the maximum eclipse magnitude.

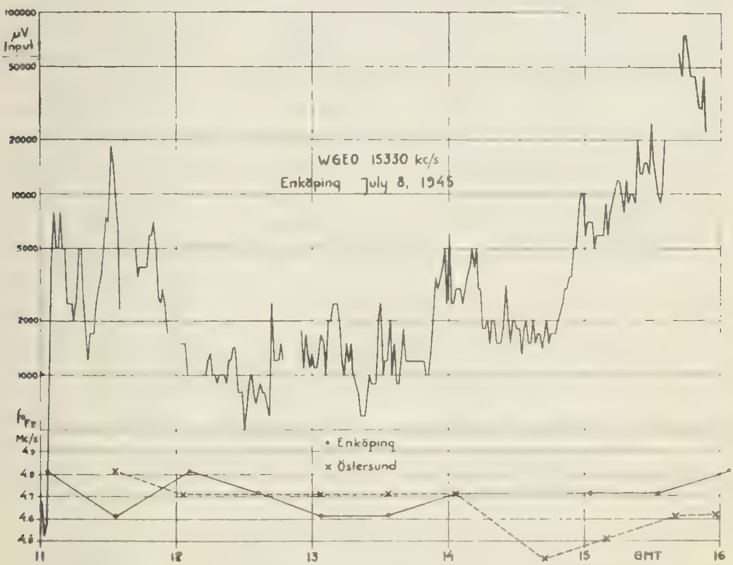

FIG. 9—QUASI-MAXIMUM SIGNAL-STRENGTHS AT ENKÖPING, AND CRITICAL FREQUENCIES F2-LAYER AT ENKÖPING AND ÖSTERSUND, JULY 8, 1945

Figures 9–11 show again the quasi-maximum signal strength recorded at Enköping. In these Figures the critical frequencies for the $F2$-layer at Östersund and Enköping are drawn for comparison. The very high values of signal strength on July 8 at $16^h\ 00^m$ GMT are associated with strong

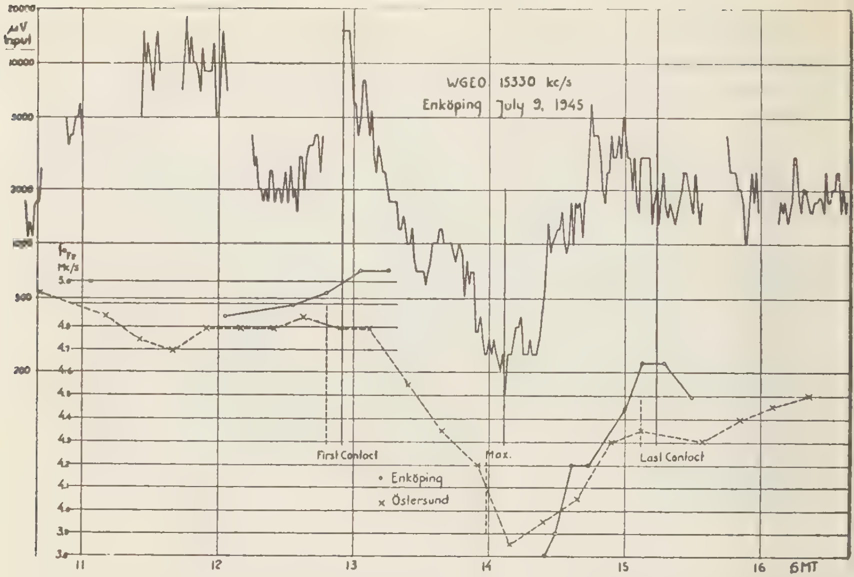

FIG. 10—QUASI-MAXIMUM SIGNAL-STRENGTHS AT ENKÖPING, AND CRITICAL FREQUENCIES F2-LAYER AT ENKÖPING AND ÖSTERSUND, JULY 9, 1945

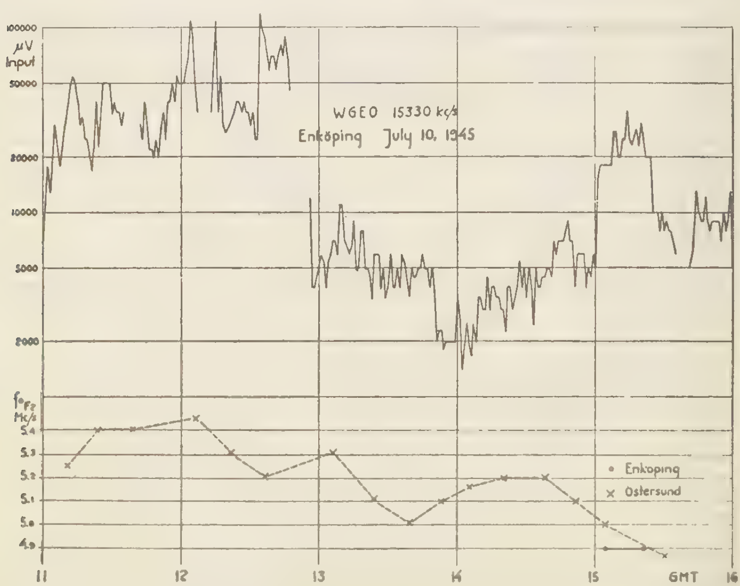

FIG. 11—QUASI-MAXIMUM SIGNAL-STRENGTHS AT ENKOPING, AND CRITICAL FREQUENCIES F2-LAYER AT ENKÖPING AND ÖSTERSUND, JULY 10, 1945

sporadic E-layers observed at Enköping. The same observation was made on the day of the eclipse. Between $11^h\ 00^m$ and $12^h\ 00^m$ GMT some high values were recorded and at that time we had strong sporadic E-layers, as mentioned before. During the eclipse the signal strengtth dropped from a mean value of about 4000–5000 μV to about 200 μV.

The conclusion to be drawn from those recordings at Enköping and Hörby is that the eclipse had a definite influence on the transmission at this frequency, 15,330 kc/s.

(6) *Field-strength measurements on medium-wave broadcast stations*—Measurements were made at Hudiksvall on the broadcast station Luleå on 392 kc/s and on the broadcast station Hörby on 1131 kc/s. Regarding Luleå the position of the measuring station was such that for one reflection on 100-km virtual height, the point of reflection was just where the totality on 100 km occurred. The day field-strength from Luleå was about 35 μV/m while the night field-strength reached the value of about 100 μV/m. During the eclipse the variations from the normal-day field-value did not exceed five per cent. Thus the night field-values were not reached.

At the same place at Hudiksvall field-strength measurements were also made on the broadcast station at Hörby on 1131 kc/s. The day field-strength from this station was so low that it was impossible to hear the station. In the night, between $22^h\ 00^m$ and $23^h\ 00^m$ Swedish time, the field strength reached values of about 6000 μV/m. During the eclipse no increase above the day value was observed. Only for a minute or two, 15 minutes after the greatest eclipse at Hudiksvall, the station could be heard but the field strength only reached the value of about ten μV/m.

The results indicate that the absorbing D-layer was not dissolved during the eclipse but still absorbed the sky-waves from both the Luleå and the Hörby station.

References

[1] Olof E. H. Rydbeck, Chalmers Solar Eclipse Ionospheric Expedition 1945, Trans., Chalmers University of Technology, Gothenburg, Sweden, No. 53 (1946).

[2] W. Stoffregen, Records of the ionosphere during the total eclipse in the north of Sweden on July 9, 1945, Terr. Mag., 51, 495-499 (1946).

[3] Leiv Harang, Radio-echo observations at Tromsö during the solar eclipse on July 9, 1945, Terr. Mag., 50, 287-296 (1945).

[4] [illegible] Grönstrand, The total sol[illegible] of 1945 July 9, Predictions for Scandinavia, Stock. Observ., Annaler, 14, No. 7.

Royal Board of Telegraphs,
Stockholm, Sweden, May, 1947

NOTES

(See also pages 468, 477, 496, and 534)

(54) *Au Tau Observatory*—The Au Tau Observatory, some 13 miles from Hongkong, was completely destroyed during the Japanese invasion. G. S. P. Haywood, Director of the Royal Observatory, recently has advised that, because of the greatly increased demands on the Observatory for meteorological services and the present financial stringency, it will not be possible to re-establish the magnetic station. Annual magnetic values for Au Tau were published to the end of 1939; the manuscript records, partly in press, for 1940 and 1941 have been lost.

(55) *Survey of New Zealand*—A recent letter from H. F. Baird, Director of the Magnetic Observatory, Christchurch, New Zealand, states he expected during December, 1947, to February, 1948, to do magnetic fieldwork. He hopes to reoccupy also Snares Island (1907) and possibly two Campbell Island stations (1907).

(56) *Instituto de Geofísico de Huancayo*—The transfer to the Government of Peru of the Huancayo Magnetic Observatory by the Carnegie Institution of Washington has now been formally completed as of July 1, 1947, by Supreme Decree of the President of the Republic of Peru. The Directive Committee which will be autonomously responsible for the operation of the Institute, designated by Supreme Decree of the President of the Republic, is under the presidency of Dr. Jorge A. Broggi, Director of the Geological Institute of Peru. The other six members of the Committee are Dr. Carlos Monge, M., Director of the Andean Biological Institute of the University of San Marcos, Engineer Ricardo Valencia, Director of Industries and Electricity of Peru, and Col. Gerardo Dianderas, Director of the Military Geographic Institute of Perù, delegated by the University of San Marcos, all at Lima, Peru; citizens of the United States on the Directive Committee are Dr. John L. Hydrich, of the Rockefeller Foundation, who is officially connected with the Department of Health and Public Welfare of Peru at Lima, Dr. Eugene Delgado, Cultural Attaché of the Embassy of the United States at Lima, and Dr. J. A. Fleming, Advisor in International Scientific Relations at the Carnegie Institution at Washington. Richard M. de Lambert, First Secretary of the Embassy of the United States at Lima, will act as alternate for Dr. Fleming in his absence.

Paul G. Ledig, whose services have been loaned by the Carnegie Institution of Washington as Observer-in-Charge since July 1, 1947, will return after a short vacation in Peru to the Department of Terrestrial Magnetism at Washington in January 1948. Engineer Alberto Giesecke, Jr., who has been associated for many years as First Assistant at the Observatory to Mr. Ledig, has been appointed Technical Director of the new Institute.

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1946

BY M. WALDMEIER

Table 1 contains the final sunspot-numbers for 1946 for the whole disk of the Sun, based on observations made at the Zurich Observatory, supplemented by series furnished by other cooperating observatories. Table 2 gives the number of spot-groups on each day for the year 1946. The yearly mean of the group-numbers is 7.8. The yearly mean of the relative-numbers is 92.6, against 33.2 in 1945. The number of spotless days has diminished

TABLE 1—*Final relative sunspot-numbers for the whole disk of the Sun for 1946*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	25	94	96	99	163	20	96	153	115	91	95	84
2	35	103	83	102	150	28	106	154	128	107	88	88
3	34	104	81	102	156	31	91	137	127	73	85	79
4	24	109	92	105	145	26	104	137	97	77	59	104
5	18	110	100	85	150	43	120	128	63	62	63	102
6	12	115	92	97	116	63	120	111	49	64	121	98
7	10	109	71	71	103	54	113	116	49	67	125	111
8	15	102	71	80	82	75	98	100	49	65	126	87
9	19	95	65	83	72	70	87	109	40	57	110	73
10	38	121	78	55	61	48	60	107	50	61	130	103
11	35	115	67	64	52	54	76	99	49	50	138	119
12	21	103	71	71	41	62	91	98	68	68	169	120
13	73	96	57	64	36	68	87	86	92	92	147	99
14	103	79	50	62	40	74	80	108	89	144	167	116
15	109	64	52	52	17	86	78	95	106	115	145	165
16	93	53	49	50	37	81	89	109	101	131	140	150
17	83	58	59	48	66	67	107	90	90	126	159	143
18	59	54	87	65	92	94	124	94	99	127	150	143
19	56	60	106	56	85	68	150	100	100	134	161	141
20	51	45	100	64	89	112	130	107	90	131	141	145
21	58	65	101	58	78	105	110	110	88	128	141	126
22	44	70	103	56	88	108	143	104	101	133	124	138
23	48	67	109	61	88	111	137	115	133	132	153	156
24	59	87	74	58	102	112	146	107	109	123	140	152
25	44	70	55	69	110	99	117	94	139	136	138	148
26	33	90	57	67	101	101	120	80	132	128	127	140
27	45	86	49	78	100	94	171	73	152	130	116	144
28	43	90	60	109	76	94	156	82	129	106	102	154
29	50		60	119	59	75	157	88	105	109	84	132
30	56		87	120	41	83	165	114	93	102	69	116
31	83		94		37		174	119		103		98
Mean	47.6	86.2	76.6	75.7	84.9	73.5	116.2	107.2	94.4	102.3	123.8	121.7

Table 2—*Daily numbers of sunspot-groups for 1946*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	3	6	10	8	16	2	12	8	10	10	8	10
2	5	5	7	9	13	2	12	9	10	11	9	7
3	4	6	6	10	12	2	7	9	12	7	9	6
4	3	6	7	9	11	2	8	9	9	8	5	11
5	2	6	7	8	10	6	8	8	6	7	8	9
6	1	6	7	10	9	7	9	10	5	6	10	9
7	1	6	6	10	9	6	7	11	4	6	10	11
8	2	7	7	9	8	8	8	9	5	6	10	9
9	2	6	6	9	6	8	6	10	3	7	8	7
10	4	10	8	7	6	6	7	8	5	6	12	8
11	4	10	7	7	5	5	7	8	5	5	13	10
12	3	10	7	8	3	6	9	9	7	7	13	8
13	8	11	6	7	3	6	6	8	7	8	10	6
14	8	8	5	6	4	8	7	11	6	13	10	7
15	9	7	6	4	1	10	6	10	5	10	11	10
16	7	5	5	5	4	8	7	12	6	12	11	8
17	6	5	6	4	7	6	8	10	5	12	13	9
18	8	5	8	6	11	9	10	8	7	12	14	8
19	5	6	10	5	9	7	12	5	7	13	15	7
20	5	4	8	7	8	13	11	8	8	13	14	8
21	5	7	9	5	7	9	7	7	6	13	13	7
22	5	7	10	4	6	8	10	8	9	11	9	10
23	5	7	11	5	8	11	9	9	13	12	10	12
24	5	10	6	4	8	10	9	9	11	10	8	11
25	3	7	5	5	7	9	4	7	12	13	8	10
26	2	10	5	6	8	9	4	7	12	12	8	9
27	3	9	4	7	9	8	8	7	14	11	8	11
28	3	10	6	10	8	8	7	7	12	11	7	10
29	4		6	14	7	7	7	6	11	10	7	11
30	5		10	13	5	10	10	8	10	10	8	8
31	6		9		5		9	9		10		9
Mean	4.4	7.2	7.1	7.4	7.5	7.2	8.1	8.5	8.1	9.7	10.0	8.9

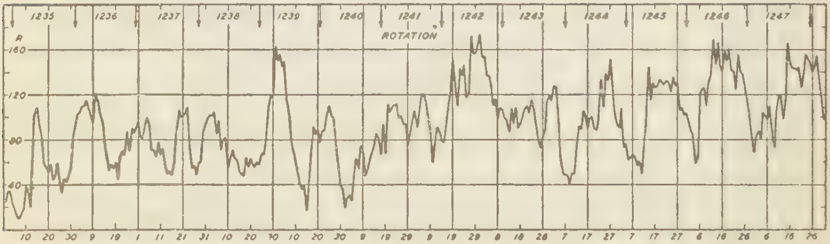

FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1946

from 16 in 1945 to zero in 1946. Figure 1 gives a graphical representation of the daily relative sunspot-numbers of 1946, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of the Figure.

EIDGEN. STERNWARTE,
Zurich, Switzerland, July 9, 1947

LETTERS TO EDITOR

(See also pages 448, 451, and 522)

K-INDICES AND SUDDEN COMMENCEMENTS, JULY TO SEPTEMBER, 1947, AT ABINGER

I enclose the list of K-indices of geomagnetic activity at Abinger for July to September, 1947, in Table 1.

Table 1 - K-indices of geomagnetic activity and magnetic character-number (C) at Abinger Observatory, July-September 1947

[Range for K = 9 is 500 γ; scale-values of variometers in γ/mm: D = 4.97, H = 4.35, Z = 4.35]

Gr. day	July 1947			August 1947			September 1947		
	Values K	Sum	C	Values K	Sum	C	Values K	Sum	C
1	3 2 2 2 3 4 3 3	22	1	3 3 4 4 2 4 3 2	25	1	3 3 2 3 2 2 3 2	20	1
2	3 3 3 3 4 5 3 3	27	1	1 2 4 3 3 4 3 3	23	1	2 1 3 4 3 2 2 4	21	1
3	1 3 3 1 2 3 2 2	17	1	2 2 2 3 2 3 3 3	20	1	4 4 7 6 5 6 5 5	42	2
4	1 3 1 3 3 2 1 0	14	0	2 3 2 3 3 3 2 2	20	1	4 4 3 4 5 5 4 3	32	1
5	1 2 1 3 2 2 1 2	14	0	1 2 2 3 3 3 2 1	17	1	3 2 3 3 3 3 4 4	25	1
6	2 1 3 2 3 4 3 2	20	1	2 2 3 4 3 3 3 3	23	1	4 2 3 3 3 4 4 3	26	1
7	2 3 1 2 3 3 3 3	20	1	2 3 2 2 3 3 3 1	19	1	4 3 4 3 5 5 6 5	35	1
8	2 2 3 4 4 4 4 3	26	1	3 2 2 2 2 2 1 0	14	1	4 3 4 3 3 3 1 0	21	1
9	2 2 3 3 3 3 3 3	22	1	1 2 3 3 1 2 1 3	16	1	3 1 1 1 2 2 2 1	13	1
10	4 2 2 2 3 4 3 3	23	1	2 1 3 3 3 3 1 3	19	1	1 1 1 1 1 2 1 0	8	0
11	3 2 2 4 4 3 3 3	24	1	2 3 3 3 4 3 1 3	22	1	0 1 2 3 3 5 4 3	21	1
12	3 3 3 2 3 3 3 2	22	1	4 4 3 5 3 4 3 4	30	1	2 2 4 3 3 2 4 3	23	1
13	3 2 2 2 3 4 3 2	21	1	3 3 3 3 3 6 4 4	29	1	4 4 4 3 3 4 4 5	31	1
14	1 2 2 1 2 3 3 2	16	1	4 2 2 3 3 3 3 3	23	1	4 4 4 5 4 5 4 5	35	1
15	3 3 2 2 2 3 3 1	19	1	0 2 2 5 5 6 5 6	31	2	4 4 5 4 5 5 5 5	37	1
16	4 1 2 1 1 2 1 1	13	1	6 3 3 5 3 4 4 4	32	2	3 3 3 1 3 3 4 5	25	1
17	1 1 2 3 2 7 8 6	30	2	4 4 4 4 4 5 5 5	35	2	5 5 4 4 4 5 5 5	37	1
18	5 4 5 5 6 6 6 5	42	2	5 5 5 5 5 4 4 4	37	2	5 4 3 3 4 5 5 5	34	1
19	4 3 3 4 4 4 4 2	28	1	3 3 4 4 5 6 4 4	33	1	3 3 4 3 3 4 4 4	28	1
20	3 4 4 4 4 5 3 3	30	1	5 3 4 3 4 5 4 3	31	1	4 3 3 3 3 4 1 4	25	1
21	3 3 3 3 4 3 3 2	24	1	5 4 3 4 3 5 4 4	32	1	3 3 3 3 3 4 3 4	26	1
22	2 2 3 3 4 4 3 3	24	1	3 3 4 8 5 5 4 3	35	2	2 3 3 4 4 5 4 4	29	1
23	3 3 4 3 4 3 3 4	27	1	6 4 3 4 5 4 4 4	34	2	4 5 4 4 5 3 2 3	30	1
24	2 4 3 3 4 4 3 2	25	1	4 3 3 4 4 3 4 4	29	1	3 4 4 3 5 7 6 5	37	2
25	3 2 3 3 4 4 4 3	26	1	3 3 4 4 4 4 3 3	28	1	6 6 5 5 5 5 5 4	41	2
26	3 4 3 3 4 4 3 3	27	1	2 2 3 3 3 2 3 3	21	1	3 3 3 3 3 2 3 3	23	1
27	2 3 4 4 4 3 3 2	25	1	3 3 4 3 2 2 1 1	19	1	4 3 2 3 3 3 2 3	23	1
28	2 1 3 2 3 2 3 2	18	1	1 1 2 2 2 3 3 4	18	1	3 2 1 3 3 3 2 3	20	1
29	2 3 2 3 4 3 2 0	19	1	4 3 3 4 3 4 2 2	25	1	1 2 2 3 2 2 1 3	16	1
30	1 2 1 2 1 2 1 2	12	1	2 3 3 2 2 2 2 1	17	1	3 2 2 2 3 2 4 3	21	1
31	1 1 1 2 3 3 3 3	17	1	1 1 3 3 3 4 3 3	21	1			

In view of the interest which is now attached to "Sudden-Commencement" phenomena, I append in Table 2 a list of the times at which these characteristic movements have appeared on the Abinger traces during the same period. The time is "Universal Time" (UT = GMT). An asterisk (*) indicates that the movement, though abrupt, was not characteristically "sudden."

TABLE 2—*Sudden-commencement phenomena at Abinger Observatory, July to September, 1947*

Month	Day and GMT (= UT)			Month	Day and GMT (= UT)		
1947	*d*	*h*	*m*	*1947*	*d*	*h*	*m*
July	17	17	48.4	Sep.	2	23	26*
Aug.	1	15	17*		4	13	46*
	12	09	05.9		5	18	02*
	15	09	50.6		15	14	54.9
	22	09	10.8		23	12	09.1
					30	18	08.2

ROYAL OBSERVATORY,
Greenwich, London, S. E. 10, England, October 9, 1947

H. SPENCER JONES,
Astronomer Royal

NOTES

(See also pages 468, 477, 492, and 534)

(57) *Gravity and geomagnetism at Pan-American Consultation on Cartography, April 11-30, 1948*—The Subcommittee on Gravity and Geomagnetism of the Pan-American Consultation on Cartography, under the presidency of Col. Gerardo Dianderas, S., will hold a meeting in Buenos Aires, Argentina, April 11-30, 1948. The agenda, include besides matters pertaining to gravity determinations, the adoption of international standards for geomagnetism, coordination of the magnetic work of observatories in the Americas and the disposition thereof, intercomparison of the magnetic instruments of the various countries of the Western Hemisphere, and discussions of a collaborative program on the instruction of personnel for geomagnetic work. Communications and reports pertaining to the agenda will be welcomed by the General Secretary (Teniente Coronel Pedro Roberto Quiroga, Instituto Geográfico Militar, Buenos Aires, Argentina); abstracts of not more than 500 words are desired to reach Buenos Aires not later than February 15, 1948.

MEAN K-INDICES FROM THIRTY MAGNETIC OBSERVATORIES AND PRELIMINARY INTERNATIONAL CHARACTER-FIGURES, C, FOR 1946

By W. E. Scott

K-indices have been received at the Department of Terrestrial Magnetism from 31 magnetic observatories for the year 1946. The records are not complete from all, but the average number reporting was 30. Those contributing (arranged in order of geomagnetic latitude) were as follows: Godhavn; College; Lerwick; Dombås; Sitka; Eskdalemuir; Rude Skov; Agincourt; Witteveen; Abinger; Srednikan; Yakutsk; Cheltenham; Zaimishche; Vyssokaya Dubrava; Moscow; Zuy; San Fernando; Tucson; Dusheti; Tashkent (Keles); San Juan; Honolulu; Alibag (the lower limit for a K-index 9 is 300γ at Alibag); Huancayo; Apia; Pilar; Hermanus; Watheroo; Toolangi; and Amberley. No reports were received for 1946 from Sodankylä, Slutsk, Chambon-la-Forêt, Zô-Sè,* and Kuyper.

The mean indices, K_M, for successive three-hour periods of the Greenwich day are given in Table 1 for the year 1946.

There was a marked increase in magnetic activity during 1946. K-indices of 9 were reported on 17 days, as follows: January 3; February 7 and 8; March 24 and 25; March 28 and 29; April 23 and 24; July 26 and 27; September 16, 18, 19, 22, and 23; and October 27. However, during no three-hourly interval was $K = 9$ observed by all observatories; the nearest approach to this condition was the interval 12^h to 15^h, March 28, when 22 observatories reported a K-index of 9. There was no perfectly calm three-hourly interval, and only one Greenwich day—November 27—when the value of K_M was 1.0 or less for all eight three-hourly intervals.

There were a number of major magnetic storms throughout the year of 1946. The most notable disturbance, comprising two distinct geomagnetic storms, occurred during March 23-29. In severity, it compared with the great storm of March 1, 1941. Other major disturbances occurred on February 7-8, April 22-24, and September 21-24, with a fairly severe storm on July 26-27, 1946. Moderate magnetic disturbances were recorded on January 3-4, March 9-11, April 12-15, May 5-11, May 20-24, September 16-19, September 27-30, and October 26-27, 1946.

The mean K-indices by months for the Greenwich day are given in Table 2 and those by years for 1940 to 1946 in Table 3. The mean for the year 1946 is 2.33, an increase of 0.42 over that for 1945.

The utilization of K-indices for currently selecting the five international

*Figures for Zô-Sè have since been received.

Table 1--Mean K-indices from thirty observatories, 1946

Day	January 1946 Values K_M								Sum	February 1946 Values K_M								Sum
1	1.5	1.6	2.4	2.9	2.6	2.8	3.1	1.9	18.8	0.8	1.2	0.7	1.4	1.5	1.7	1.2	1.1	9.6
2	2.7	1.4	1.2	1.9	2.0	3.2	2.4	0.7	15.5	2.5	2.6	2.7	2.2	2.0	1.4	1.8	1.7	16.9
3	0.4	0.9	4.1	6.3	6.0	6.8	5.6	5.0	35.1	1.1	1.2	1.1	1.4	3.9	2.9	3.1	3.0	17.7
4	4.6	4.2	4.8	3.7	2.8	4.7	4.2	3.8	32.8	2.1	1.7	2.0	2.7	3.3	2.9	1.6	2.9	19.2
5	2.6	2.3	2.2	1.9	2.3	1.7	2.0	2.2	17.2	2.3	2.5	1.7	1.3	2.6	3.1	2.5	3.1	19.1
6	2.7	1.1	2.0	1.7	1.8	3.5	3.1	1.7	17.6	2.7	1.2	1.6	1.8	3.5	1.5	2.8	2.6	17.7
7	0.5	1.2	0.8	1.9	2.0	2.1	3.1	1.5	13.1	2.7	1.8	3.3	7.3	6.9	7.0	6.0	7.3	42.3
8	1.4	1.5	1.3	1.1	0.9	1.1	1.8	0.9	10.0	7.4	6.3	5.7	6.2	5.2	5.1	3.5	2.4	41.8
9	0.8	0.6	1.1	1.3	1.9	1.4	1.3	0.8	9.2	1.0	1.0	3.0	3.2	2.8	2.3	2.4	2.8	18.5
10	0.6	1.6	1.7	2.4	1.9	2.5	1.9	1.2	13.8	1.5	2.7	3.8	2.5	3.2	2.8	2.1	1.5	20.1
11	2.0	4.2	4.0	3.8	2.6	2.2	2.7	3.1	24.6	1.8	2.0	1.5	1.5	2.5	1.5	2.0	0.8	13.6
12	1.9	1.7	1.5	2.7	1.7	1.6	2.5	1.7	15.3	0.9	1.5	0.8	1.4	2.0	2.6	2.6	3.1	14.9
13	0.5	0.9	0.5	1.1	1.4	0.9	2.1	1.2	8.6	1.9	1.6	3.4	3.5	3.3	1.8	0.9	0.5	16.9
14	0.6	1.4	0.8	1.1	0.7	1.0	0.8	0.8	7.2	0.9	1.7	4.8	4.3	2.3	4.2	4.5	3.6	26.3
15	0.9	0.8	1.2	1.0	1.1	1.6	1.6	2.5	10.7	3.1	4.1	3.4	2.3	2.7	2.1	2.1	1.4	21.2
16	2.5	2.8	2.0	1.3	2.0	1.5	1.3	1.6	15.0	1.4	1.4	1.5	1.5	2.2	1.9	2.3	2.5	14.7
17	1.3	2.0	3.2	2.1	1.0	2.7	3.2	2.9	18.4	2.6	2.8	2.3	1.1	0.9	1.0	0.9	0.8	12.4
18	0.9	1.0	1.6	2.2	2.9	3.0	3.2	2.9	17.7	1.5	1.3	1.3	1.1	1.5	2.5	2.6	1.3	13.1
19	3.2	2.5	1.7	2.0	1.5	1.1	2.1	2.1	16.2	2.6	3.4	4.1	3.3	2.6	3.9	4.6	4.1	28.6
20	1.6	1.8	0.9	0.7	0.7	0.5	0.4	0.4	7.0	1.8	2.2	1.6	2.4	1.6	2.4	3.6	5.1	20.7
21	0.4	0.5	0.5	0.5	1.2	1.2	1.7	2.5	8.5	4.6	3.6	4.6	4.6	5.0	4.6	3.4	1.5	31.9
22	2.8	2.8	3.2	2.0	2.5	1.2	1.0	2.7	18.2	3.5	3.4	3.2	3.1	2.8	2.5	2.5	2.1	23.1
23	2.1	2.2	2.6	2.5	2.5	1.7	2.3	4.5	20.4	2.6	3.0	3.7	3.3	3.4	3.1	3.5	1.4	24.0
24	3.0	3.0	3.4	3.6	4.9	4.3	3.8	3.3	29.3	1.7	1.0	1.7	2.4	2.0	1.4	3.6	3.0	16.8
25	2.2	1.5	1.4	1.5	3.4	3.3	2.9	1.5	17.7	2.4	2.7	2.2	3.0	2.3	2.2	1.9	2.3	19.0
26	2.0	2.8	3.2	2.9	2.3	4.2	3.0	1.1	21.5	1.9	1.5	1.5	2.2	1.4	2.1	2.1	1.8	14.5
27	1.7	1.9	1.5	1.0	1.3	1.0	1.3	1.2	10.9	0.7	0.9	0.9	1.1	0.6	1.4	1.0	0.7	7.3
28	0.8	0.6	1.1	1.7	1.3	1.0	1.4	2.1	10.0	1.2	1.2	1.5	1.3	1.1	0.8	1.5	1.2	9.8
29	1.4	2.3	1.9	2.2	2.8	1.8	1.6	1.2	15.2									
30	1.8	1.7	1.7	2.1	1.9	1.2	1.9	1.8	14.1									
31	1.5	1.1	1.8	1.4	2.0	2.7	1.4	2.1	14.0									

Day	March 1946 Values K_M								Sum	April 1946 Values K_M								Sum
1	3.8	4.5	4.5	3.5	1.8	1.9	1.5	2.5	24.0	3.7	2.4	3.5	2.6	2.1	1.9	2.9	2.6	21.7
2	4.1	3.0	2.7	3.2	2.4	1.5	1.1	1.8	19.8	3.0	2.9	2.7	3.2	3.3	2.9	2.8	3.3	24.1
3	1.5	1.5	1.5	0.9	1.2	1.0	2.0	1.8	11.4	1.1	0.9	1.6	1.9	2.2	2.6	2.2	1.7	14.2
4	2.3	2.1	2.8	3.2	3.0	2.8	3.6	4.3	24.1	2.1	1.8	1.4	1.8	2.0	1.6	1.2	2.2	14.1
5	3.7	2.8	2.5	3.3	3.8	3.4	2.5	2.6	24.6	1.7	1.3	1.5	1.8	2.7	2.5	3.2	2.1	16.8
6	2.5	2.7	2.9	3.0	3.1	2.8	2.5	2.8	22.3	1.8	1.8	1.6	2.1	2.3	1.7	2.3	2.2	15.8
7	2.3	1.7	2.2	2.9	2.9	1.9	2.1	1.6	17.6	2.5	2.7	2.5	2.6	3.0	3.0	1.8	1.1	19.2
8	0.9	1.0	1.0	0.8	1.4	1.6	2.6	2.0	11.3	1.0	1.5	2.8	2.9	2.3	1.3	2.7	2.3	16.8
9	0.7	1.1	1.0	1.1	2.6	4.5	4.1	2.7	17.8	2.4	1.9	2.9	4.5	4.4	4.4	2.8	3.9	27.2
10	4.9	4.7	4.2	4.0	4.6	4.0	5.2	4.8	36.4	3.2	1.6	1.4	3.0	2.1	1.0	0.8	1.6	14.7
11	4.7	3.0	3.0	3.1	3.4	3.1	3.0	3.4	26.7	1.0	1.1	1.7	1.7	1.6	1.3	1.1	1.4	10.9
12	1.4	1.3	1.5	1.2	1.2	1.1	0.8	0.7	9.2	1.8	1.8	1.1	2.2	2.5	2.5	2.8	4.1	18.8
13	0.7	1.5	1.0	1.9	1.6	2.0	2.3	1.4	12.4	3.4	3.1	3.5	3.1	2.6	2.5	3.8	3.1	25.1
14	1.0	1.3	0.8	1.8	1.8	1.3	2.5	1.0	11.5	2.6	1.4	2.0	3.8	5.0	3.2	3.0	3.4	24.4
15	1.4	0.9	2.3	3.1	2.9	2.4	2.1	1.8	16.9	4.4	3.7	4.8	4.5	5.5	4.7	4.4	1.8	33.8
16	0.6	0.7	1.5	1.2	1.9	1.6	1.5	2.2	11.2	2.0	2.2	1.4	1.2	1.3	1.5	2.4	3.0	15.0
17	3.2	3.7	2.6	2.5	3.9	3.6	3.8	2.9	26.2	2.5	1.6	1.4	1.5	2.5	1.2	1.0	0.9	12.6
18	2.0	1.4	2.0	2.7	2.2	2.0	1.8	0.8	14.9	1.3	1.5	1.8	2.5	2.5	1.9	1.8	0.8	14.1
19	0.9	1.4	1.8	1.2	1.5	1.1	2.1	2.6	12.6	0.7	0.8	1.7	1.0	1.0	1.9	1.5	2.0	10.6
20	2.6	1.6	1.3	3.1	3.3	2.4	2.2	2.1	18.6	1.6	0.9	0.6	1.4	1.7	2.2	1.3	0.8	10.5
21	2.3	3.4	2.3	2.9	2.7	1.8	1.1	0.8	17.3	0.7	0.9	1.3	1.2	1.9	1.3	1.4	0.9	9.6
22	0.8	2.9	4.7	4.2	3.9	2.3	2.6	4.2	25.6	0.8	1.0	3.7	3.8	2.5	3.3	4.1	1.8	21.0
23	3.1	2.4	2.0	1.5	2.4	3.2	3.4	5.0	23.0	2.8	3.3	4.1	5.1	5.5	6.2	5.6	7.0	39.6
24	6.8	5.8	3.9	4.8	5.8	6.4	3.3	4.2	41.0	6.4	5.8	5.4	5.3	3.9	5.4	3.8	3.0	39.0
25	6.0	5.3	5.3	6.4	6.9	7.1	6.6	613	49.9	4.2	3.2	2.3	1.4	0.9	0.7	0.7	0.8	14.2
26	5.2	4.5	4.3	4.3	3.1	3.5	4.3	2.6	31.8	1.9	1.4	1.7	1.5	1.3	1.9	2.2	2.9	14.8
27	3.7	3.6	1.7	2.9	3.4	4.0	2.9	3.8	26.0	3.7	1.7	1.2	1.0	0.7	0.5	0.8	0.7	10.3
28	4.1	4.7	7.9	8.3	8.8	8.2	7.5	6.7	56.2	1.4	1.1	1.2	1.8	2.0	2.9	3.7	2.6	16.7
29	5.1	4.3	4.4	4.0	3.4	2.8	2.2	2.3	28.5	1.5	1.2	3.3	3.1	1.8	2.0	1.6	2.0	16.5
30	1.9	1.6	1.4	2.0	1.4	1.5	1.9	2.0	13.7	2.1	1.1	1.1	1.0	2.0	1.2	1.7	1.1	11.3
31	1.3	1.8	2.9	3.1	2.6	1.7	1.8	3.5	18.7									

Table 1--Mean K-indices from thirty observatories, 1946--continued.

Day	May 1946 Values K_M	May 1946 Sum	June 1946 Values K_M	June 1946 Sum
1	0.9 2.0 2.3 1.4 1.6 2.2 2.6 2.5	15.5	1.8 1.9 2.0 1.5 1.7 1.5 2.0 1.7	14.1
2	3.1 1.7 2.0 1.7 1.6 1.9 1.4 1.6	15.0	2.3 1.3 1.5 1.5 1.4 1.4 1.3 0.8	11.5
3	1.9 2.2 1.6 1.4 1.1 1.8 2.6 1.9	14.5	0.8 0.8 1.0 1.1 1.2 0.8 0.6 0.5	6.8
4	2.5 1.8 2.1 3.0 1.9 2.1 2.2 1.5	17.1	0.7 1.5 2.6 2.1 3.1 2.1 0.8 0.4	13.3
5	1.2 1.7 1.2 0.9 1.6 1.5 2.2 3.5	13.8	0.4 0.5 0.9 1.2 1.3 1.0 3.9 3.6	12.8
6	3.2 4.5 4.6 3.8 2.7 3.3 2.5 5.4	30.0	2.9 2.7 2.5 3.3 3.5 1.8 1.6 1.3	19.6
7	3.4 5.2 4.7 3.8 3.5 2.5 1.8 2.1	27.0	2.2 1.3 2.8 4.6 5.6 4.7 3.7 2.4	27.3
8	2.4 3.9 4.9 3.2 4.4 3.0 3.2 3.2	28.2	3.5 2.9 3.2 4.3 4.2 4.6 2.9 3.6	29.2
9	3.7 3.6 3.9 3.4 4.2 4.6 4.0 3.8	31.2	3.8 3.7 3.1 2.8 3.4 3.0 2.1 2.1	24.0
10	2.2 3.2 3.7 3.3 2.7 2.7 1.9 3.3	23.0	1.5 1.3 1.5 1.5 2.3 3.3 2.1 1.3	14.8
11	3.5 4.2 5.7 4.6 4.5 4.2 2.2 1.9	30.8	2.0 2.6 2.7 3.2 2.8 2.0 2.3 1.7	19.3
12	2.1 1.9 1.8 2.6 2.0 1.6 2.0 1.6	15.6	1.3 2.6 3.2 3.3 3.9 3.9 3.2 3.8	25.2
13	2.8 2.9 2.1 1.2 1.0 1.3 1.5 2.5	15.3	2.6 3.4 3.0 3.5 3.3 2.1 1.7 1.1	20.7
14	2.1 1.8 0.9 0.8 1.6 1.4 1.3 0.7	10.6	1.7 2.1 3.0 1.9 2.0 1.6 2.5 1.4	16.2
15	0.9 1.2 1.5 2.1 1.9 1.5 1.5 1.4	12.0	0.5 1.3 2.5 2.0 2.6 2.1 2.1 1.2	14.3
16	1.7 1.9 1.5 2.2 2.9 1.3 2.3 2.1	15.9	1.4 1.3 2.6 3.0 3.0 2.5 3.2 4.1	21.1
17	2.5 3.2 2.1 2.0 3.0 3.1 2.4 1.4	19.7	4.6 4.3 3.6 2.0 1.9 1.6 1.7 2.7	22.4
18	3.1 2.8 3.4 3.0 2.8 3.1 1.6 1.3	21.1	3.4 2.5 2.4 2.7 2.0 3.5 3.3 3.5	23.3
19	0.7 0.9 1.0 1.6 0.9 1.2 0.6 0.8	7.7	4.0 3.8 4.1 3.9 3.9 3.1 3.2 3.0	29.0
20	0.5 0.9 1.3 1.1 1.2 2.5 3.1 4.5	15.1	3.0 2.3 2.3 2.2 2.7 2.2 2.1 1.3	18.1
21	3.9 3.0 4.0 3.6 3.6 3.8 3.7 3.2	28.8	2.4 3.6 3.6 2.8 1.7 2.1 2.9 2.9	22.0
22	2.7 5.0 4.8 4.2 4.0 3.8 3.7 3.6	31.8	2.8 2.0 1.3 2.2 3.0 2.7 2.8 1.2	18.0
23	4.2 3.1 3.2 3.7 4.1 4.3 4.2 3.6	30.4	1.2 1.1 2.8 1.9 1.2 1.0 0.7 0.5	10.4
24	3.1 3.1 2.8 3.3 3.6 3.7 2.5 2.9	25.0	0.7 1.1 1.0 1.2 0.8 0.7 2.1 2.0	9.6
25	3.5 2.9 2.6 2.2 2.2 2.8 2.3 2.5	21.0	1.8 2.6 2.8 2.8 1.6 2.7 2.4 1.4	18.1
26	3.2 3.1 1.5 2.4 2.9 2.0 1.3 1.3	17.7	1.6 2.2 2.0 2.0 3.5 2.8 2.4 2.4	18.9
27	1.6 1.5 1.8 1.1 1.1 1.2 1.1 2.1	11.5	1.9 1.9 3.3 3.3 2.5 2.9 3.8 3.6	23.2
28	2.2 2.3 2.4 1.8 2.4 2.4 2.1 1.3	16.9	2.2 3.8 3.1 2.0 2.9 2.3 3.0 2.9	22.2
29	1.9 2.4 2.5 2.1 1.9 2.0 2.1 1.4	16.3	2.8 3.3 3.5 3.4 4.0 5.0 5.0 3.5	30.5
30	1.8 1.1 1.3 1.6 2.0 2.0 2.1 2.1	14.0	1.3 1.9 1.5 1.6 2.2 1.8 1.7 0.8	12.8
31	2.6 2.8 3.6 2.5 2.3 2.0 2.2 1.6	19.6		

Day	July 1946 Values K_M	July 1946 Sum	August 1946 Values K_M	August 1946 Sum
1	0.8 0.8 0.8 1.2 1.8 1.6 1.2 0.7	8.9	2.0 1.7 1.6 1.2 2.0 1.9 1.7 1.2	13.3
2	1.3 2.4 2.6 2.3 2.7 1.7 1.4 1.5	15.9	1.3 1.4 1.4 1.5 1.6 1.3 1.8 1.3	11.6
3	2.3 3.0 4.0 3.6 2.9 2.4 1.7 1.3	21.2	1.1 1.8 1.6 1.7 1.4 1.5 1.3 0.9	11.3
4	1.1 1.4 1.0 1.9 2.7 1.4 1.0 0.4	10.9	1.1 1.2 1.2 1.3 1.5 1.6 1.6 0.9	10.4
5	1.0 1.0 1.1 0.9 1.5 1.5 0.8 0.8	8.6	0.9 1.0 1.7 2.2 1.9 1.7 2.1 1.5	13.0
6	1.7 1.1 1.3 1.4 1.7 2.0 1.5 1.4	12.1	1.5 1.3 1.4 2.4 3.1 1.8 1.6 1.7	14.8
7	1.9 4.4 4.3 4.8 3.3 3.8 4.0 3.7	30.2	2.6 3.0 2.8 2.6 4.2 4.0 4.0 2.2	25.4
8	3.5 2.6 2.4 3.4 3.6 3.9 1.9 1.5	22.8	2.0 1.7 1.3 0.9 1.0 2.7 2.4 2.2	14.2
9	4.1 3.0 2.6 4.0 2.7 3.0 3.0 2.3	24.7	2.5 1.2 1.3 2.0 1.6 2.1 2.1 1.2	14.0
10	2.1 1.9 1.6 2.7 1.8 3.1 2.1 2.6	17.9	0.8 0.9 0.9 1.7 1.4 2.0 2.4 2.5	12.6
11	2.8 2.8 2.2 2.5 2.5 2.7 2.9 2.3	20.7	2.8 3.6 4.0 3.0 4.3 3.9 3.2 3.4	28.2
12	1.4 1.8 2.3 1.7 1.7 1.5 1.2 0.7	12.3	3.4 2.4 3.3 1.7 1.4 2.0 1.9 3.6	19.7
13	0.7 0.9 1.0 2.0 1.7 1.6 1.0 1.7	10.6	2.5 2.2 2.3 1.5 1.4 1.6 2.6 1.8	15.9
14	1.0 1.7 2.7 2.8 4.4 4.2 2.7 2.4	21.9	2.0 2.7 4.1 4.2 4.4 2.6 4.4 4.2	28.6
15	2.5 4.1 2.7 2.1 2.0 2.1 1.5 1.1	18.1	4.1 3.1 2.4 3.2 2.8 3.5 3.4 3.1	25.6
16	1.4 1.1 1.5 3.9 2.9 3.6 2.4 2.6	19.4	2.8 2.4 2.6 3.1 2.2 2.3 4.4 3.9	23.7
17	3.3 3.0 3.2 3.0 3.0 2.3 1.7 2.3	21.8	2.1 3.0 3.8 3.8 4.0 3.1 2.4 3.1	25.3
18	2.1 1.9 2.0 3.7 4.6 5.2 4.4 3.9	27.8	1.5 1.1 1.6 1.5 1.5 1.4 1.7 2.0	12.3
19	3.8 3.6 3.2 3.4 4.2 2.0 2.4 2.3	24.9	2.8 1.6 1.5 1.5 1.8 1.3 1.9 1.5	13.9
20	2.4 1.8 1.0 0.9 1.2 1.4 1.5 1.8	12.0	1.5 2.2 1.2 1.5 1.6 1.4 1.7 0.9	12.0
21	1.9 2.1 1.8 1.9 2.3 2.9 2.1 2.7	17.7	1.0 1.3 1.2 1.4 0.8 0.7 0.7 1.4	8.5
22	2.1 3.1 2.1 2.1 2.7 2.8 2.4 3.2	20.5	1.0 1.1 0.6 0.7 0.6 0.7 0.6 0.6	5.9
23	3.1 2.4 2.5 4.4 3.4 3.1 2.5 2.3	23.7	0.7 0.8 0.9 1.3 1.0 0.8 0.7 0.9	7.1
24	1.3 1.7 1.3 1.8 2.2 1.5 1.6 1.3	12.7	1.6 2.0 3.0 1.2 1.7 1.5 1.4 1.9	14.3
25	2.1 2.5 2.8 3.1 1.9 3.7 3.2 2.9	22.2	2.4 2.1 1.9 1.5 1.2 1.3 0.9 0.6	11.9
26	3.4 3.6 3.0 3.4 3.1 3.1 7.5 7.1	34.2	1.1 0.8 1.3 1.2 0.9 1.1 1.6 0.6	8.6
27	7.8 7.5 7.1 5.3 4.4 3.2 2.8 2.4	40.5	1.0 1.9 2.2 2.1 2.0 1.0 1.2 1.8	13.2
28	1.9 2.2 2.2 2.1 3.5 2.8 3.3 3.7	21.7	1.5 1.9 1.0 0.9 1.4 1.8 1.9 0.7	11.1
29	4.1 4.8 4.3 3.8 3.6 5.5 4.2 3.5	33.8	0.9 0.8 0.9 0.8 0.7 1.3 1.0 1.0	7.4
30	4.5 3.8 3.4 3.8 4.4 3.8 2.2 1.7	27.6	0.6 0.5 0.5 0.8 0.9 1.2 2.7 3.9	11.1
31	2.8 1.5 1.4 1.8 1.6 2.1 1.3 1.8	14.3	4.5 5.6 4.9 3.3 4.0 3.4 2.5 1.8	30.0

Table 1--Mean K-indices from thirty observatories, 1946--concluded

Day	September 1946									October 1946								
	Values K_M								Sum	Values K_M								Sum
1	1.1	0.9	1.0	1.9	2.0	1.8	1.3	1.3	11.3	2.5	2.4	3.5	3.3	3.1	3.0	3.2	1.8	22.8
2	2.2	1.9	3.1	1.5	1.3	1.5	2.7	1.9	16.1	1.2	2.5	2.8	1.9	3.4	2.5	2.1	1.5	17.9
3	2.0	1.2	1.1	1.8	1.8	2.6	2.3	2.9	15.7	2.4	3.1	2.6	1.7	2.9	3.2	1.2	0.9	18.0
4	2.3	2.4	3.2	4.0	3.3	2.8	2.3	3.0	23.3	2.3	2.3	2.2	2.5	2.3	2.9	2.2	1.6	18.3
5	2.4	1.3	2.6	2.9	3.1	3.1	1.8	2.2	19.4	1.1	2.3	2.1	2.3	4.1	3.7	3.7	1.2	20.5
6	2.4	2.6	1.4	1.0	0.9	0.5	0.6	0.5	9.9	2.1	2.6	3.1	3.1	2.1	2.3	3.6	3.2	22.1
7	0.7	1.4	3.2	3.6	3.8	2.5	3.0	2.6	20.8	2.4	2.2	2.5	3.2	3.3	3.1	2.2	1.3	20.2
8	2.0	1.6	2.8	2.7	2.6	1.8	2.7	2.5	18.7	1.6	2.1	1.2	0.9	0.8	1.4	2.0	2.2	12.2
9	2.2	2.5	1.8	1.4	2.6	3.7	3.9	2.2	20.3	3.0	3.9	4.0	4.0	3.1	2.2	2.8	4.1	27.1
10	2.2	1.5	3.7	3.8	3.1	1.9	1.5	3.7	21.4	2.5	1.2	2.2	2.7	2.5	1.7	3.2	2.9	18.9
11	2.1	2.0	1.9	3.0	2.5	2.8	2.9	2.2	19.4	2.3	2.2	1.3	1.5	2.7	2.4	2.5	1.9	16.8
12	1.8	1.7	3.0	2.9	2.8	1.9	2.2	2.5	18.8	2.7	3.2	3.0	1.1	1.1	1.1	1.5	2.2	15.9
13	1.6	2.6	1.6	1.3	2.2	1.5	1.9	2.2	14.9	2.4	1.3	1.4	1.2	0.9	0.8	0.7	1.7	10.4
14	2.4	1.1	1.8	2.1	1.4	1.2	1.9	2.4	14.3	1.6	1.1	2.6	1.7	1.6	2.0	1.9	1.4	13.9
15	1.4	1.8	2.5	1.4	1.5	2.5	1.4	1.2	13.7	0.7	1.0	1.7	2.7	1.9	1.1	1.6	2.2	12.9
16	1.3	1.5	1.1	1.7	3.5	4.9	5.6	4.4	24.0	1.3	1.4	2.2	2.6	1.9	1.6	2.2	2.6	15.8
17	4.4	3.6	2.4	2.4	1.9	3.0	3.4	4.7	25.8	1.1	1.3	2.1	1.1	1.2	0.8	1.3	1.1	10.0
18	6.2	5.7	5.4	5.5	5.8	5.9	5.8	4.2	44.5	1.6	1.0	0.8	0.8	0.9	0.8	0.9	1.6	8.4
19	4.8	5.1	3.2	3.9	5.7	4.9	2.9	3.0	33.5	0.9	1.4	1.1	1.5	1.4	1.8	2.7	3.7	14.5
20	2.9	2.0	3.0	2.3	1.4	2.2	2.7	2.0	18.5	3.3	3.6	3.3	3.2	2.9	2.8	3.8	3.0	25.9
21	2.5	1.4	1.1	2.6	2.5	4.9	3.9	3.9	22.8	2.1	1.5	1.3	1.5	1.3	2.1	2.7	2.4	14.9
22	3.3	7.0	6.6	8.0	8.6	7.7	5.6	5.0	51.8	1.9	1.4	2.2	1.9	2.3	1.3	1.2	1.1	13.3
23	6.1	5.9	6.0	4.7	5.5	6.6	4.9	5.2	44.9	1.8	2.0	2.3	2.1	2.3	1.8	0.8	1.2	14.3
24	4.1	3.2	2.9	3.4	3.0	2.8	1.8	0.9	22.1	1.2	1.0	1.0	2.0	3.1	1.8	1.6	1.7	13.4
25	1.0	1.0	1.3	1.5	1.5	1.3	1.6	1.2	10.4	2.1	1.3	2.3	2.1	1.3	2.4	1.8	2.4	15.7
26	1.0	1.3	1.7	2.3	2.2	2.2	1.1	1.8	13.6	2.9	3.0	3.4	3.3	3.1	2.9	3.3	5.1	27.0
27	2.5	2.3	3.9	3.7	3.4	5.2	5.0	4.2	30.2	5.3	4.5	4.0	4.1	4.4	4.6	3.3	3.5	33.7
28	3.6	4.4	4.9	4.3	5.3	6.1	5.4	5.3	39.3	2.5	2.0	2.6	2.2	2.3	2.9	1.8	1.7	18.0
29	5.1	3.3	2.6	2.2	3.5	4.0	4.0	3.4	28.1	2.4	2.0	1.6	2.8	2.1	1.9	2.4	2.4	17.6
30	3.4	3.9	3.5	3.7	3.3	3.8	4.2	2.6	28.4	1.0	1.0	1.9	1.7	1.0	1.7	0.6	0.7	9.6
31										0.6	0.7	2.8	2.9	4.2	4.0	2.9	2.6	20.7

Day	November 1946									December 1946								
	Values K_M								Sum	Values K_M								Sum
1	2.6	2.7	3.0	3.9	3.6	4.0	3.2	3.9	26.9	1.0	1.1	0.7	0.6	1.2	2.7	2.5	2.5	12.3
2	1.4	1.8	3.1	2.3	2.2	1.2	2.1	1.9	16.0	1.9	1.3	1.4	1.3	2.4	2.1	2.1	2.7	15.2
3	1.9	1.2	1.9	0.8	1.3	1.2	0.7	1.5	10.5	3.1	2.2	1.7	2.2	1.6	1.3	0.9	0.8	13.8
4	1.4	0.8	0.8	2.4	1.9	1.4	1.6	2.3	12.6	1.0	1.4	1.6	1.0	1.5	1.8	2.2	1.7	12.2
5	1.0	1.9	2.2	3.7	3.5	2.9	3.2	2.5	20.9	1.7	1.9	2.4	2.8	2.9	3.5	2.5	2.5	20.2
6	2.5	2.6	3.1	4.0	4.3	4.0	2.3	3.2	26.0	2.2	2.3	1.7	1.3	1.6	1.3	1.9	2.6	14.9
7	2.9	2.5	1.5	1.3	1.4	1.7	1.1	0.8	13.2	2.5	3.0	2.5	1.3	1.3	3.1	2.5	1.9	18.1
8	0.9	0.8	1.0	1.4	2.2	1.2	1.6	2.3	11.4	2.0	2.9	1.5	2.3	1.3	1.0	1.2	0.9	13.1
9	2.4	1.6	1.7	2.4	2.5	1.8	1.7	2.9	17.0	1.3	1.2	1.2	1.1	1.3	1.5	2.1	1.1	10.8
10	2.7	1.5	1.3	1.2	1.8	2.1	3.7	3.2	17.5	1.7	1.3	1.5	2.8	3.0	3.3	2.4	2.7	18.7
11	3.5	3.4	2.6	3.4	1.8	1.8	2.6	2.9	22.0	1.7	1.4	1.4	2.7	2.8	3.0	4.1	3.4	20.5
12	3.2	3.7	2.7	2.0	1.8	2.8	2.9	1.4	20.5	2.5	1.5	1.1	3.2	3.0	3.4	2.5	2.6	19.8
13	1.3	1.4	1.2	1.4	1.4	1.5	2.1	2.4	12.7	1.8	1.4	2.4	1.6	2.5	2.4	1.6	1.1	14.8
14	0.8	0.8	0.8	1.4	2.1	1.2	1.3	1.6	10.0	0.7	1.0	1.0	0.9	1.1	0.8	0.5	0.7	6.7
15	0.7	0.7	3.7	2.9	3.2	3.1	3.1	3.3	20.7	0.6	0.7	0.8	1.4	1.4	1.0	1.0	0.9	7.8
16	3.0	3.2	2.7	2.3	2.1	1.8	2.6	3.0	20.7	1.0	0.7	1.2	1.2	1.2	1.3	1.7	2.7	11.0
17	1.3	2.0	0.8	1.0	1.3	1.6	1.5	2.5	12.0	2.1	1.9	2.4	2.5	2.7	1.4	1.6	2.2	16.8
18	2.0	1.3	1.3	2.1	1.6	1.3	0.8	2.1	12.5	2.2	1.8	2.2	1.4	1.9	1.4	1.8	1.4	14.1
19	2.8	2.1	2.8	3.3	2.4	2.8	3.0	4.1	23.3	2.5	2.4	3.5	3.5	4.3	4.4	3.4	1.3	25.3
20	2.1	2.6	1.9	2.4	3.9	3.0	3.2	3.0	22.1	1.9	2.0	1.1	1.2	0.9	0.7	0.6	0.8	9.2
21	3.6	2.4	3.2	4.5	4.2	2.9	2.9	3.3	27.0	1.1	1.2	2.7	3.9	2.8	2.4	1.1	2.1	17.3
22	2.8	2.7	2.8	2.1	1.8	3.5	1.6	1.6	18.9	2.5	2.8	2.9	2.8	2.7	2.6	1.3	1.2	19.8
23	2.1	2.0	1.9	2.2	2.5	1.2	0.8	0.9	13.6	0.9	2.7	2.4	2.4	2.9	1.7	1.4	1.9	16.3
24	1.0	3.8	3.4	3.7	5.5	3.6	2.0	1.4	24.4	1.9	2.0	1.5	1.0	1.4	1.2	0.7	1.0	10.7
25	1.7	2.8	2.7	3.0	3.6	4.1	3.9	2.9	24.7	1.3	1.4	1.2	1.2	1.2	0.9	3.3	4.2	14.7
26	2.6	2.9	1.6	1.2	1.7	2.7	1.1	0.7	14.5	1.5	1.8	2.1	3.3	2.9	3.1	2.0	1.7	18.4
27	1.0	0.7	0.8	1.0	0.5	0.7	0.7	0.6	6.0	1.8	2.6	2.4	2.0	1.7	1.4	3.3	2.8	18.0
28	0.7	0.9	1.9	1.2	1.4	1.0	1.2	1.2	9.5	2.5	1.9	2.1	1.7	2.3	1.4	1.1	1.2	14.2
29	1.1	0.7	0.8	0.6	0.9	0.5	0.7	1.1	6.4	1.3	1.4	1.9	1.4	2.1	2.2	1.2	1.3	12.8
30	1.0	0.7	0.8	0.9	1.9	1.1	0.8	1.6	8.8	0.9	1.0	0.8	1.0	0.8	1.1	0.9	0.7	7.2
31										1.5	1.3	1.1	1.2	1.8	1.5	1.2	1.5	11.1

TABLE 2—*Mean K-indices by months from thirty observatories, 1946*

Month	Mean indices, K_M, for GMT 3-hour interval								
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	Mean
January	1.71	1.80	1.98	2.08	2.13	2.24	2.28	2.03	2.03
February	2.19	2.20	2.49	2.62	2.68	2.60	2.59	2.34	2.46
March	2.76	2.65	2.71	2.97	3.06	2.85	2.80	2.81	2.83
April	2.31	1.92	2.24	2.48	2.50	2.37	2.38	2.24	2.30
May	2.42	2.64	2.67	2.44	2.49	2.48	2.26	2.34	2.47
June	2.10	2.25	2.51	2.49	2.64	2.43	2.44	2.09	2.37
July	2.46	2.56	2.43	2.76	2.77	2.76	2.37	2.25	2.54
August	1.86	1.88	1.95	1.86	1.95	1.89	2.06	1.88	1.92
September	2.70	2.60	2.81	2.92	3.07	3.25	3.01	2.84	2.90
October	2.03	2.02	2.29	2.25	2.31	2.21	2.18	2.16	2.18
November	1.93	1.94	2.00	2.20	2.34	2.12	2.00	2.20	2.09
December	1.70	1.73	1.75	1.88	2.02	1.96	1.83	1.81	1.84
Year	2.18	2.18	2.32	2.41	2.50	2.43	2.35	2.25	2.33

TABLE 3—*Mean K-indices by years from 1940 to 1946*

Number of observatories	Year	Mean indices, K_M, for GMT 3-hour interval								
		00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	Mean
27	1940	2.12	2.05	1.95	2.09	2.24	2.29	2.34	2.22	2.16
29	1941	2.21	2.14	2.20	2.28	2.31	2.34	2.39	2.35	2.28
28	1942	2.14	2.08	2.13	2.29	2.38	2.37	2.28	2.22	2.24
27	1943	2.40	2.35	2.49	2.60	2.53	2.48	2.42	2.36	2.45
30	1944	1.96	1.87	1.93	2.04	2.06	2.03	1.96	1.95	1.98
30	1945	1.84	1.79	1.83	1.98	2.02	2.00	1.95	1.88	1.91
30	1946	2.18	2.18	2.32	2.41	2.50	2.43	2.35	2.25	2.33
Mean		2.12	2.07	2.12	2.24	2.29	2.28	2.24	2.18	2.19

quiet and disturbed days is being continued. The selected days for the year 1946 have appeared in previous issues of this JOURNAL.

It is hoped that it will be found possible to publish in detail the eight K-indices for successive three-hour periods of the Greenwich day for all collaborating observatories. It is realized that such a publication would be voluminous and entail considerable effort and expense, but it is believed would conform to the provisions of the original resolution adopted at the Washington Assembly of the International Association of Terrestrial Magnetism and Electricity in September, 1939. Moreover, such a publica-

Table 4—*Preliminary International Character-Figures, C, for 1946* *(data from 40 observatories)*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0.8	0.0	1.1	0.8	0.2	0.2	0.1	0.2	0.2	0.9	1.1	0.2
2	0.7	0.4	0.7	0.8	0.3	0.2	0.2	0.1	0.3	0.5	0.4	0.2
3	1.9	0.8	0.1	0.3	0.2	0.0	0.8	0.1	0.4	0.4	0.1	0.2
4	1.5	0.7	1.0	0.2	0.3	0.3	0.1	0.0	0.8	0.3	0.2	0.2
5	0.4	0.6	1.1	0.4	0.4	0.5	0.1	0.2	0.5	0.8	0.8	0.8
6	0.6	0.5	0.7	0.3	1.3	0.7	0.2	0.3	0.3	0.8	1.2	0.2
7	0.6	2.0	0.5	0.5	1.3	1.4	1.4	1.0	0.9	0.6	0.3	0.6
8	0.2	2.0	0.2	0.3	1.2	1.2	1.0	0.4	0.5	0.2	0.1	0.2
9	0.1	0.5	0.9	1.2	1.2	0.9	1.1	0.3	0.9	1.2	0.4	0.1
10	0.3	0.6	1.7	0.3	0.8	0.4	0.5	0.3	0.6	0.4	0.7	0.6
11	1.0	0.1	1.1	0.1	1.4	0.5	0.4	1.3	0.5	0.3	0.6	0.9
12	0.4	0.6	0.0	0.7	0.2	1.2	0.2	0.6	0.4	0.3	0.7	0.8
13	0.1	0.6	0.1	1.1	0.2	0.7	0.2	0.4	0.2	0.1	0.2	0.3
14	0.0	1.3	0.2	1.1	0.1	0.3	0.9	1.4	0.2	0.2	0.1	0.0
15	0.2	0.8	0.7	1.6	0.1	0.3	0.5	0.9	0.1	0.2	1.0	0.0
16	0.3	0.3	0.2	0.3	0.2	0.9	0.8	1.0	1.4	0.4	0.7	0.2
17	0.7	0.3	1.2	0.2	0.6	1.0	0.5	1.0	1.2	0.1	0.2	0.4
18	0.8	0.3	0.4	0.2	0.6	0.8	1.4	0.2	2.0	0.1	0.2	0.3
19	0.5	1.3	0.3	0.1	0.1	1.2	1.1	0.3	1.5	0.4	0.8	1.3
20	0.1	1.1	0.6	0.1	0.7	0.4	0.1	0.2	0.5	1.1	0.8	0.1
21	0.2	1.4	0.5	0.0	1.2	0.8	0.4	0.0	1.0	0.4	1.3	0.7
22	0.6	0.8	1.2	0.9	1.5	0.5	0.6	0.0	2.0	0.2	0.7	0.6
23	0.9	1.0	1.0	1.9	1.4	0.1	0.9	0.0	1.9	0.3	0.3	0.4
24	1.4	0.6	1.9	1.9	1.0	0.1	0.1	0.4	0.8	0.3	1.2	0.1
25	0.8	0.5	2.0	0.6	0.6	0.5	0.7	0.2	0.1	0.4	1.1	0.8
26	0.9	0.2	1.4	0.3	0.4	0.5	1.8	0.1	0.1	1.3	0.4	0.7
27	0.2	0.0	1.1	0.3	0.1	0.8	2.0	0.2	1.4	1.6	0.0	0.7
28	0.2	0.1	2.0	0.5	0.4	0.8	0.9	0.2	1.7	0.5	0.0	0.3
29	0.3		1.3	0.4	0.4	1.5	1.5	0.0	1.2	0.5	0.0	0.2
30	0.2		0.2	0.1	0.3	0.2	1.2	0.4	1.1	0.1	0.1	0.0
31	0.3		0.6		0.6		0.2	1.4		1.0		0.1
Mean	0.55	0.69	0.84	0.58	0.62	0.63	0.71	0.42	0.82	0.51	0.52	0.39

Mean for year: 0.61

tion would be of great assistance in fully evaluating the usefulness of the K-system in the measurement of magnetic fluctuations and as a form of abstract to supplement the ordinary tabulations of the hourly mean values for observatories, as well as for special studies, such as, for example, whether

a universal-time daily variation of geomagnetic activity is superposed on local-time variations. Consideration also should be given to the final publication of daily magnetic characters C.

Character-figures on a scale of 0, 1, and 2 have been received from 40 observatories. Preliminary international character-figures, C, for 1946 are given in Table 4. The average for the year is 0.61 as compared with a value of 0.47 for 1945 from 41 observatories.

The writer takes this opportunity to express his appreciation of the wholehearted cooperation given at all times by various organizations and observatories.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., October 17, 1947

REVIEWS AND ABSTRACTS

Hans G. Macht: *Das erdmagnetische Feld der Polargebiete.* Zeitschrift für Meteorologie, 1, Heft 10, 289-297 (1947).

The permanent geomagnetic field of the polar zones, especially the north-polar distribution of horizontal force (H-field) is discussed. The formal computations are based on the "canonic-development" of the magnetic potential, $\varphi = \Sigma\varphi_n$. The obvious deviation of the north-polar H-isodynamics from ideal geomagnetic parallels and of the magnetic meridians from great circles, that is, the elliptic and parabolic deformation of these lines is expressed principally by the two beginning terms $\varphi_1 + \varphi_2$. This "idealized" $(\varphi_1 + \varphi_2)$-field is troubled by different additional disturbances, further distorting the isomagnetic curves of the north-polar region.

The last chapter refers to the physical meaning of the φ_2-part of geomagnetic potential (canonic form). The magnetic coefficient $\bar{n}$ contained in the analytic Expression of φ_2 (spherical harmonic, sectorial term of second order) has not only a formal significance; furthermore, a real physical meaning must be imputed to $\bar{n}$. Being an invariant in regard to the direction of the magnetic axis, $\bar{n}$ expresses the so-called "regular part" of the Earth's inhomogeneous magnetization. This (regular part) is introduced here as "absolute cross magnetization" to the magnetic axis, a new conception

representing a fundamental constituent of the permanent field beside the main part of the Earth's homogeneous magnetization.

Author

M. Burgaud, S. J. et Z. T. Lou: *Carte magnétique de Chine*, Observatoire de Zi-Ka-Wei. Etudes sur le magnétisme terrestre, Etude 40, 74 pp. No. 10 (1937).

In preparing this publication, the following magnetic observations were utilized: Those from the Carnegie Institution of Washington from 1906 to 1917; from Messrs. Zu-tsen, Filchner, Brown, Kwei, Burgaud, Kiong, Chen, and Lou, from 1922 to 1936. The observations were reduced to mean of day and to January 1 of the year of observation. Careful examination was made of the diurnal changes as exhibited by the records of the magnetic observatories, in order to reduce to mean of day. Where observations were made at stations remote from magnetic observatories, use was made of observations at nearby repeat-stations. An attempt was also made to allow for change in rate of the annual variation with the sunspot-cycle.

In declination, four charts were prepared showing the secular variation and covering the periods 1909-15, 1915-20, 1920-30, and 1930-36. Two isogonic charts for declination appear relating to the epochs 1915 and 1936.

Three charts of secular variation in horizontal intensity were included covering the periods 1908-17, 1917-22, and 1922-36. A chart of lines of equal horizontal intensity appears for the epoch 1936. Two charts of secular variation in vertical intensity were included covering the periods 1908-1922 and 1922-1936. A chart of lines of equal vertical intensity appears for the epoch 1936.

Rather complete data in regard to anomalous areas appear on the charts, and in addition this phase of the magnetic results is covered in the text. An important part of the publication is the table giving the magnetic results at field-stations. These results are tabulated in parts, covering eight separate areas of China, and give for each area a list of repeat-stations and a list of ordinary observation stations. Rather complete data are tabulated in regard to observed values and annual changes.

The results at 385 stations are tabulated and 63 of these stations are repeat-stations. The data contained in the table of results of observations at field-stations are exhibited in detail on eight charts covering the whole area of China.

H. Freeborn Johnston

PRELIMINARY REPORT ON THE MAGNETIC RESULTS OF A JOURNEY TO SIKKIM AND SOUTHERN TIBET

By K. Wienert

Summary—The main result is a table giving declination, horizontal intensity, and dip for 55 stations in Sikkim and Southern Tibet, reduced to the epoch 1939.0. The data were obtained by the author on the Schaefer Expedition in 1938-39. Details are given on the instruments used, and the manner of reduction. Linear formulas for a smoothed normal field in the area are derived for D, H, I, and Z. Numerous observations of vertical intensity with an Askania field-balance are used for a preliminary description of local anomalies.

(1) *Conditions of observation*—The data given in this paper were collected in the years 1938 and 1939 on an expedition to Sikkim and Tibet, under Dr. Ernst Schaefer, who had gathered experience on two previous expeditions to Western China and Eastern Tibet together with the well known American explorer Brooke Dolan. All members of the expedition were biologists except the author. The original task assigned to him was to get geographical and meteorological data for the biologists. Because of interest in magnetic exploration, the author decided to take along a full set of instruments and to perform a survey of this magnetically unknown region.

As the main interest of the expedition was in biology there were some difficulties with regard to the organization of the magnetic work due to conflicting interests of members of the party. Besides, the character of the country was not very favorable to magnetic work. The Himalaya is known as one of the areas with the heaviest rainfall in the world. Work was started in June, 1938, just at the beginning of the rainy season. Cloudy skies impeded the astronomical observations. Destroyed bridges and spoiled roads hindered proper transportation. The altitudes at stations in the Himalaya were between 12,000 and 19,000 feet; this was an osbtacle at the beginning but after a period of four weeks I had become perfectly acclimatized. The winter climate of Sikkim and Tibet is ideal for any geodetic and astronomical operations from the end of September until the beginning of May. However, stormy and cold weather make life very unpleasant for a traveler whose only housing consists of a tent.

In Sikkim there were no restrictions on the work. On the trip to Tibet scientific investigations had been prohibited by the Tibetan Government and the work had to be done secretly. On the journey from Gangtok to Lhasa observations were made during the nights. At Lhasa, under the careful watching of Tibetan officials, absolute observations could be made only twice. On March 19, 1939, when we left Lhasa, the program was changed to start at 04^h, to reach the new station at $09^h\ 30^m$ and to complete observa-

tions at 21^h. Camps were at adequate distance from inhabited places, so that nobody was able to find out what was actually done. The instruments were always kept hidden in the tents and the astronomical universal was put on the tripod only when necessary. If these activities had been discovered by the Tibetan authorities, this would have meant the end of the expedition.The Tibetan as an individual is rather harmless and extremely helpful, but in congregations, especially when involved in religious service, he becomes easily excited and dangerous.

Under such circumstances perfect work was nearly impossible. Because of limits of time, observations had to be made in the most time-saving manner and it was not possible to select the best possible time for each element. Repeat-stations could be made in Sikkim. In Tibet a repetition was only possible between Gangtok and Gyantse.

(2) *Observations of position and time*—The astronomical observations, azimuth and altitude, were made by means of a Hildebrandt theodolite (Der kleine Hildebrandt) which gave bearings in full, and altitudes in half minutes of arc. For azimuth the Sun was observed in the morning or evening when it was close to the horizon. In Tibet, where the observations were made often during the night, Polaris was used. The mean error of a full set of azimuth observations was found to be about $\pm 0.'7$. Latitude and longitude were derived from altitudes of star or Sun. For the computation use was made of Sumner's method which gave a convenient control of every pointing. The two chronometers, made by Lange and Soehne of Glasshuett, were controlled by means of short-wave time-signals received with a three-tube short-wave set especially designed for the expedition. Due to this fact there was never any doubt about the rate of the watches and their correction. It was possible to pick up time-signals at nearly every hour of the day with a maximum error of ± 0.2 second. Thus it was possible to get good results for longitude. The mean error of the position of a station was found to be $\pm 0'.5$ for longitude as well as for latitude. As Sikkim is geodetically well surveyed, characteristic points were chosen for the absolute stations which were easily to be found on the map and to read the geographical coordinates from it. On the route from Gangtok to Lhasa only slight differences were found between the map and the observations, which seldom exceed the mean error of the observation. At the other stations differences of longitude amounted up to $15'$ in the maximum. The differences of latitude were always below $4'$.

The atmospheric pressure was determined with a hypsometer and four aneroids made by Fuess of Berlin-Steglitz. The corrections of the two boiling-point thermometers were negligible. The differences between the readings and the actual atmospheric pressure did not exceed 0.1 mm. The aneroids were compared with the boiling-point thermometers at least once every day when traveling. Only two of the aneroids were of satisfactory

accuracy. The calculation of the heights was carried out by means of the tables of Robitzsch making use of all necessary corrections. The reference-stations were Darjeeling and Leh for which monthly means were available until April, 1939. For the rest of the time the monthly means of 1938 were employed. For Sikkim the maximum error of a single station was found to be ±60 feet and in Tibet about ±150 feet in height. A proper reduction of the observations using daily readings of the atmospheric pressure and the temperature of the above-mentioned stations and those of Yatung, Gyantse, and Lhasa, will reduce the maximum error to about ±30 or ±40 feet for Sikkimese as well as for Tibetan observations.

(3) *Declination observations*—A magnetometer designed by Professor R. Bock of Potsdam, and fabricated by Gustav Schultze of Potsdam, was used for the observation of the declination. This instrument was especially designed for traveling purposes, and permitted to read bearings with an accuracy of 0′.1. It could be leveled roughly by means of a circular level and precisely with a striding level. The declination-magnet is a hollow cylinder which is 5.4 cm long and weighs 19 gr. In the middle is a cylindrical hole, vertical to the axis of the magnet in which a double agate cup glides up and down so as to make possible reversal of the magnet and to eliminate collimation. The ends of the magnet are shielded with mirrors which reflect the scale of the diaphragm of the reading telescope. The pivot of the declination-house can be exchanged as soon as it becomes dull. The proper position of the pivot can be controlled by means of a gage. A full set for declination consisted of observations of azimuth-marks, usually eight readings of the magnet in alternately erect and inverted position with telescope north, observations of azimuth-marks, and the same number of readings of the magnet with telescope south. The set was concluded by readings of the azimuth-marks. The statistical error of a whole set was less than ±0′.5 due to the high horizontal intensity which reduces the effect of friction to an unimportant amount. It is only in lower latitudes that the pivot-declinometer can successfully compete with an instrument with fiber suspension.

Table 1 shows the results of the standardization at the base-stations.

TABLE 1—*Standardizations of pivot-declinometer at base-stations*

Station	Date	Index-error	No. sets
		′	
Niemegk...........	Mar. 19, 1938	−4.4	2
Dehra Dun.........	July 20, 1939	−3.5	1
Niemegk...........	Nov. 20, 1939	+1.2	2
Adopted value for journey 1938–39...	....	−4.0	

At Dehra Dun three sets were observed, but two of them had to be rejected since they were observed during periods of high Potsdam range-indices. The result of the standardizations shows that the index-error was not subject to any serious change during the period of the expedition. The reason for the excessive high change from $-3'.5$ to $+1'.2$ during the transport from Dehra Dun to Niemegk can only be sought in a mechanical distortion of the upper part of the magnetometer or the declination-house. Although the observations at Dehra Dun could only be reduced by means of estimated diurnal and secular variations, credit was given to them and a final index-error of $-4'.0$ assumed for the period of the expedition.

All observations were reduced to the daily mean by use of diurnal variations derived from the five quiet days of Dehra Dun for the years 1936 and 1937. For the reduction to the epoch 1939.0 a secular change of $-2'.7$ per year was adopted for the area of the expedition.

In order to find the mean error of a single determination under full action of all errors, such as astronomical determination of azimuth, magnetic measurement, and correction for diurnal and secular change, the results at the repeat-stations are given in Table 2. All observations which were made in periods with high Potsdam range-indices were rejected.

All repeat-stations combined give a mean error for one set of $\pm 1'.2$.

TABLE 2—*Mean errors of a single determination of declination (D) at repeat-stations*

No.	Station	Date	*D* at 1939.0	Mean	Error of mean
			° ′	° ′	′
1	Gangtok	June 14, 1938	−0 35.5		
		Dec. 12, 1938	−0 35.8		
		Dec. 13, 1938	−0 37.0		
		Dec. 18, 1938	−0 35.0		
		July 6, 1939	−0 38.1	−0 36.3	±0.6
4	Chungtang	July 2, 1938	−0 13.5		
		Dec. 5, 1938	−0 17.2	−0 15.4	±1.9
5	Lachen	Sep. 4, 1938	−0 24.8		
		Nov. 10, 1938	−0 22.8	−0 23.8	±1.0
27	Kalashar	Jan. 1, 1939	−0 24.8		
		June 23, 1939	−0 25.0	−0 24.9	±0.1
30	Sakang	Jan. 4, 1939	−0 27.5		
		June 16, 1939	−0 26.4	−0 27.0	±0.6
31	Gyantse	May 26, 1939	−0 22.6		
		June 6, 1939	−0 25.2	−0 23.9	±1.3

Furthermore, Table 2 makes a serious change of the index of error of the magnetometer during the period of the journey appear unlikely.

(4) *Horizontal-intensity observations*—For the determination of the horizontal intensity (H), the declination-house of the magnetometer was exchanged for a house for oscillation and another one for deflection. The deflection-bars are held together by a strong ring which fits in a ring on the magnetometer. The position of the bars is precisely defined and can exactly be reproduced. Deflection-observations are made in Lamont's first position at two distances, namely, 24 cm and 18 cm. The shorter distance was used only when there was sufficient time for such observations. The results of the shorter distance were not calculated because of the lack of temperature-factors and exact determination of the constants.

Before deflections, as well as oscillations, were observed, a torsion-weight was put in the stirrup and the line of no torsion carefully adjusted so as to be parallel to the optical axis of the reading telescope within a few tenths degree. This work was rather tedious, but was never omitted in order to avoid any influence on the quality of the results. This was the more necessary as the suspension fiber consisted of platinum-iridium wire of a diameter 0.02 mm, which produced a rather high torsion-factor.

The deflection-magnets were protected by iron boxes out of which they were taken at least one hour before the beginning of the observations. The deflection-observations were made in the following order: (1) Magnet east, north pole east; (2) magnet east, north pole west; (3) magnet west, north pole west; (4) magnet west, north pole east. This mode of observation makes linear variations of declination ineffective. Each position was read twice. During the first set of deflections the deflection-magnet was inserted in erect and during the second one in inverted position. The suspended magnet was always kept in the same position. The temperature of the deflection-magnet was read to 0°.1C.

Determinations of the temperature-factors for deflections at the longer distances were made twice, at Niemegk in 1938 and 1939. Since the shorter distance gave an infinite deflection-angle at Niemegk, the temperature-factors were determined at Dehra Dun but not are yet calculated because of the lack of information on variations. The factors were calculated by means of the method of least squares. The logarithmic results of the observations are given in Table 3. Each result is based at least on two temperature-cycles.

A combination of former observations made by Errulat and Bock in 1934 gave 0.0002077 for Magnet I and 0.0002235 for Magnet II. For the reduction of the deflection-angle to a temperature of 20°C the results of Table 3 were employed. Furthermore the deflection-angle was reduced to the daily mean of the horizontal intensity in the same way as with the observations of declination.

After having finished the deflection-observations, the deflection-bars

Table 3—*Summary of temperature-factor determinations*

Magnet	Date	Temp.-range	Log. temp.-factor
		°C	
I	Mar. 20 to 21, 1938	+7 to +24	0.0002128
I	Nov. 24 to 26, 1939	+7 to +30	0.0002092
	Mean value for Magnet I		0.0002110
II	Nov. 26 to 27, 1939	+9 to +31	0.0002237

and the deflection-house were removed and replaced by the oscillation-house, which consisted mostly of non-metallic material in order to avoid damping of the arc of vibration of the magnet. The arc of vibration was kept below 1°. Thus the reduction to infinitesimal arc could be omitted. The rate of the observation-watch was controlled by wireless time-signals at the beginning and the end of the oscillation-observations. With each deflection-magnet, two sets of oscillations were observed, one in erect and the other in inverted position. The mean error of one set, as derived from the differences of the two positions, was found to be $\pm 4 \times 10^{-4}$ second of time. The time of oscillation was also reduced to a temperature of +20°C and the daily mean value of the horizontal intensity. The torsion-factor was determined at nearly every station. The observed values were inserted in a graph with time of oscillation and torsion-factor as coordinates. For the reduction of the observations the torsion-factor was read from the average curve of the graph.

The temperature-factor for oscillations was not calculated in the usual way from the deflection-factor but was directly observed at the observatory of Ningst near Hamburg. In order to get more accurate results a chronograph was used for the determination of the time of oscillation. Eight sets were observed with Magnet I. The temperatures ranged from +6°.3 to +23°.7C. With Magnet II, 14 sets were observed at temperatures from +5°.1 to +24°.8C. The logarithmic temperature-factors, deduced by means of the method of the least squares, were 0.0001192 for Magnet I and 0.0001262 for Magnet II. These values were used for the reduction of the observations of the expedition. The result of a calculation from the deflection temperature-factors by use of the temperature-coefficients of brass and steel, following the procedure of Venske which is newly recommended by Bock, is 0.0001134 for Magnet I and 0.0001197 for Magnet II, that is, there is a serious difference between calculation and observation which considerably exceeds the error of observation and which can only be explained by differences of actual and assumed temperature-coefficient of brass and steel.

For the calculation of the horizontal intensity, the reduced values of the deflection-angle and the time of oscillation were inserted in formula (1).

$$\log H = \log C_i - (1/2) \log \sin \varphi_{20} - \log T_{20} \ldots\ldots\ldots (1)$$

H = horizontal intensity, φ_{20} = deflection-angle at 20°C, T_{20} = time of oscillation at 20°C, C_i = constant of the magnetometer including the effect of induction. From stations where deflections and oscillations were observed, the constant C_d for those stations where only deflections were determined was deduced by means of formula (2).

$$\log C_d = \log \sin \varphi_{20} + \log H \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In this way 35 values for log C_d were obtained which were graphed against time. From this average curve the value of log C_d was read for those stations where only deflections had been determined. Formula (3) applied for these stations.

$$\log H = \log C_d - \log \sin \varphi_{20} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Observations for standardization were made at Niemegk in 1938 and 1939, and at Dehra Dun in 1939. The results are shown in Table 4 (the meaning of C is explained below).

TABLE 4—*Standardizations for log C_i and log C*

Station	Year	Magnet I		Magnet II	
		log C_i	log C	log C_i	log C
Niemegk......	1938	9.64094	9.64155	9.64141	9.64198
Dehra Dun....	1939	9.64065	9.64161	9.64109	9.64197
Niemegk......	1939	9.64047	9.64108	9.64084	9.64140
Assumed for journey 1938–39..............		9.64058	9.64158	9.64106	9.64198

The observations of Dehra Dun could only be reduced in the above outlined primitive way. The value of H for July, 1939, was calculated from values of 1935, 1936, and 1937, and found to be 0.33300 cgs.

The induction-coefficients were determined by Dr. Fanselau of Potsdam. The logarithmic values found were: Magnet I, 8.01693; Magnet II, 7.98931. From log C_i the value of log C, the constant in which the influence of induction is eliminated, was derived by means of formula (4).

$$\log C = \log C_i - (1/2) \log \frac{(1 - kH \sin \varphi_{20})}{(1 + kH)} \ldots\ldots\ldots\ldots (4)$$

k is the induction-coefficient.

From the values of log C, it may be inferred that no considerable change took place during the journey in Sikkim and Tibet. Therefore the means of the standardizations at Niemegk (1938) and Dehra Dun (1939) were adopted for the expedition. Log C_1 may be considered as constant for the area of the expedition. It was calculated from log C by the formula (4). For H, an average value of 0.356 cgs was assumed. The large change of log C between Dehra Dun (1939) and Niemegk (1939) can be explained by the rough transport which probably caused mechanical distortions of the magnetometer or changed the distribution-coefficient of the magnets.

Absolute determinations (observations of deflections and oscillations) were made 35 times during the expedition. As explained above, the results of the formula give the daily mean. For the reduction to 1939.0 a secular change of $+45\gamma$ per year was adopted. The results obtained from measurements with Magnet II are on the average 16γ higher than those with Magnet I. Since the uniformity of the observational procedure was carefully maintained, it is hard to find a reason for this systematic difference. No significant correlation was found between the differences of the results of Magnet I and Magnet II and either temperature, or temperature-changes, during a set of observations, or the time (local mean time as well as the period of the year), or the Potsdam range-index. This investigation also proved that the temperature-coefficients are of sufficient accuracy.

Relative measurements (only observations of deflections) were made 38 times. The results obtained from Magnet II are, on the average, 11γ higher than those of Magnet I.

The mean error of one set of observations for absolute as well as for relative measurements, as derived from the differences of the results of the two magnets, was found to be $\pm 8\gamma$. Table 5 represents the results at the repeat-stations. Absolute measurements are marked *a*, relative determinations by *r*.

From Table 5, the mean error of a single determination of H was found to be about $\pm 20\gamma$. The results of Lachung have not been included, because the high Potsdam range-index indicates that the large difference between the two observations may be due to magnetic storms.

The quality of the H-determinations was much affected by the large temperature-changes which were caused by the excessively strong radiation of the Sun. Changes of 15°C during one set were not seldom observed. Under such conditions the temperature of the air surrounding the magnet, which is measured and used for the reduction of the readings, differs much from the actual temperature of the instrument and the magnets. It is evident that corrections for temperatures are somewhat uncertain. A second roof on the observation tent would greatly diminish the temperature-changes.

(5) *Dip observations*—The dip was observed by means of a dip-circle

TABLE 5—*Mean errors of a single determination of horizontal intensity (H) at repeat-stations*

No.	Station	Date	H, at 1939.0	Potsdam range-index	Mean H at 1939.0	Error of mean
			cgs		*cgs*	γ
1	Gangtok	June 15, 1938	0.35971[r]	2–2		
		Dec. 12, 1938	0.36009[a]	2–2		
		July 6, 1939	0.35992[a]	4–2	0.35991	±11
4	Chungtang	June 30, 1938	0.35752[r]	2–1		
		July 1, 1938	0.35798[a]	3–5		
		Dec. 5, 1938	0.35772[a]	1–1	0.35774	±13
5	Lachen	Sep. 3, 1938	0.35702[a]	2–1		
		Oct. 18, 1938	0.35712[r]	2–1		
		Nov. 10, 1938	0.35664[r]	1–1	0.35693	±15
10	Tebleh	Sep. 25, 1938	0.35671[a]	1–2		
		Oct. 5, 1938	0.35612[r]	0–1	0.35642	±30
12	Geokang	July 19, 1938	0.35549[a]	2–1		
		Oct. 9, 1938	0.35590[r]	1–1	0.35570	±20
17	Lachung	Oct. 24, 1938	0.35858[a]	3–1		
		Dec. 3, 1938	0.35773[a]	4–5	0.35816	±43
23	Gotsa	Dec. 27, 1938	0.35834[r]	2–5		
		July 1, 1939	0.35886[r]	2–2	0.35860	±26
27	Kalasher	Jan. 1, 1939	0.35551[a]	1–1		
		June 22, 1939	0.35561[a]	2–1	0.35556	± 5
29	Kangmar	Jan. 3, 1939	0.35470[r]	1–1		
		June 18, 1939	0.35506[a]	2–3	0.35488	±16
30	Sakang	Jan. 4, 1939	0.35499[r]	0–1		
		June 16, 1939	0.35446[r]	4–2	0.35472	±26
31	Gyantse	May 26, 1939	0.35417[a]	3–2		
		June 4, 1939	0.35419[a]	3–3	0.35418	± 1
37	Lhasa	Jan. 27, 1939	0.35049[a]	0–1		
		Mar. 6, 1939	0.35004[a]	1–1	0.35026	±22
52	Shigatse	May 5, 1939	0.35228[a]	1–2		
		May 18, 1939	0.35229[a]	1–1	0.35228	± 1

made by Carl Bamberg of Berlin-Friedenau, lent to me by Professor Bartels, then Director of the Geophysical Institute at Potsdam. The instrument was provided with two needles, which were used in eight different positions. The mean error of one set as derived from repeat-stations amounted to $\pm 3'$ for needle BI and to $\pm 4'.3$ for needle BII. For this reason double weight was placed upon the results derived from needle BI.

The standardization-measurements were made at Dehra Dun in July, 1939. The index-errors were deduced from four complete sets and found to be for Needle BI, $-5'.6$, and for Needle BII, $+17'.8$. Diurnal variations for the reduction of the observations were not available. The dip for Dehra Dun, at 1939.5, was derived from the values of 1935, 1936, and 1937. A value of 45° 39′ was assumed. For the investigation of the mean error of a

Table 6—*Mean errors of a single determination of inclination (I) at repeat-stations*

No.	Station	Date	*I*, at 1939.0	Mean *I*	Error of mean
			° ′	° ′	′
1	Gangtok	June 14, 1938	40 04.0		
		Dec. 13, 1938	40 07.3		
		Dec. 18, 1938	40 04.1		
		July 7, 1939	40 01.1	40 04.2	±1.2
4	Chungtang	July 2, 1938	40 30.1		
		July 3, 1938	40 30.1		
		Dec. 12, 1938	40 23.7	40 28.0	±2.1
5	Lachen	Sep. 5, 1938	40 47.5		
		Oct. 19, 1938	40 39.7		
		Nov. 11, 1938	40 39.4	40 42.2	±2.7
12	Gayokang	July 20, 1938	41 07.5		
		July 21, 1938	41 03.3	41 05.4	±2.1
16	Camp Thanggu	July 14, 1938	41 06.9		
		July 15, 1938	41 09.3	41 08.1	±1.2
31	Gyantse	May 29, 1939	42 33.2		
		June 10, 1939	42 28.9	42 31.0	±2.2
37	Lhasa	Feb. 3, 1939	43 36.8		
		Feb. 5, 1939	43 35.0	43 35.9	±0.9
52	Shigatse	May 3, 1939	43 05.6		
		May 3, 1939	43 09.9		
		May 16, 1939	43 08.2	43 07.9	±1.2

full set with both needles the results of all repeat-stations are listed in Table 6.

From this the mean error of a full set of dip with both needles was found to be $\pm 2'.5$. The largest deviation from the mean amounted to $5'.3$. Due to the large error of the dip-determinations no reductions because of diurnal and secular variations were made.

The dip-circle was very sensitive against dust. Since Tibet is desert-like, measurements could be made only as long as the wind kept below Beaufort strength 4, that is, as long as there was no dust in the air. On slight traces of dust, the instrument reacted with confusing results. Therefore dip-measurements could not be made at a number of stations. For these stations the dip was calculated from horizontal and vertical intensity, the latter being observed at every station with Schmidt's field-balance. Results of this kind are marked by *c* in Table 7, which summarizes the final results.

(6) *Linear formulas for the normal field*—From the above it may be inferred that only the measurements of the declination are of the desired accuracy. The horizontal-intensity determinations will be considerably improved by the use of variations deduced from the magnetograph records of Dehra Dun. But this reduction will only be effective as long as no magnetic storms occurred during the observations. The dip-observations can scarcely be improved by any further reductions. The accuracy is inadequate from the point of view of a theoretical investigator with regard to the normal field, etc.

An attempt was made to deduce normal-field formulas from the observations by the method of least squares. As the number of the stations is small, these normal fields can give only a general idea about the tendency of the magnetic elements in the region concerned. The formulas for the normal field refer to a zero-point in longitude 89° 30′ east and latitude 28° 20′ north and differences in latitude ($\Delta\varphi$) and longitude ($\Delta\lambda$) are expressed in degrees and decimals thereof.

In the computations of the normal-field formulas the numbers of undisturbed stations selected were: D, 31; H, 40; I, 54 [the dip-value at Penam Dzong (No. 54) had to be rejected because the absolute station there is seriously disturbed]. The resulting formulas are as follows:

$$
\begin{array}{llll}
\text{Normal } D = & -25'.6 & +4'.6(\Delta\varphi) & +6'.4(\Delta\lambda) \\
 & \pm 1'.3 & \pm 2'.7 & \pm 1'.4 \\
\text{Normal } H = & 35556\,\gamma & -350\,\gamma(\Delta\varphi) & +25\,\gamma(\Delta\lambda) \\
 & \pm 38\,\gamma & \pm 12\,\gamma & \pm 35\,\gamma \\
\text{Normal } I = & 41^\circ\,37'.8 & +95'.2(\Delta\varphi) & +1'.1(\Delta\lambda) \\
 & \pm 1'.6 & \pm 3'.6 & \pm 2'.4
\end{array}
$$

(7) *Vertical-intensity observations and normal field*—The vertical intensity was measured with an old-type field-balance by the Askania Werke

TABLE 7—*Magnetic elements, epoch 1939.0*

No.	Name of place	Latitude, north	Longi-tude, east	Height	D	H	I
		° ′	° ′	feet	° ′	cgs	° ′
1	Gangtok	27 20.0	88 37.3	5780	−0 36	0.3599	40 04
2	Dikchu	27 24.0	88 31.4	2000	−0 39	0.3599	40 15[c]
3	Singhik	27 31.0	88 33.7	4500	−0 52	0.3583	40 23[c]
4	Chungtang	27 36.4	88 38.8	5250	−0 15	0 3577	40 28
5	Lachen	27 43.8	88 32.9	8830	−0 24	0.3579	40 42
6	Yaktang	27 46.6	88 27.8	11380	−0 25	0.3573	40 46[c]
7	Yabuk	27 45.7	88 24.2	12990	−0 23	0.3569	40 45[c]
8	Bauer's Base Camp	27 46.0	88 20.6	14900	−0 22	0.3568	40 54
9	Goma	27 54.1	88 15.1	16400	−0 33	0.3558	41 07
10	Tebleh	27 52.9	88 24.3	14500	−0 24	0.3564	40 56
11	Latok	28 01.4	88 29.5	17000	−0 24	0.3563	41 14
12	Gayokang	28 00.4	88 35.5	15850	−0 32	0.3557	41 04
13	Gayamthashana Tso	28 03.8	88 38.6	16310	−0 24	0.3556	41 05[c]
14	Gordama Lake	28 02.0	88 43.8	16960	−0 21	0.3556	41 02[c]
15	Lhamo Lake	28 01.4	88 46.7	16860	−0 20	0.3544	41 09
16	Camp Thanggu	27 54.8	88 32.8	15550	......	0.3565	41 08
17	Lachung	27 41.6	88 44.4	8660	−0 30	0.3582	40 35[c]
18	Yumtang	27 49.6	88 42.5	11910	−0 17	0.3567	40 42
19	Mome Samdong	27 55.0	88 42.3	15090	−0 16	0.3559	40 52
20	Donky La Camp	27 58.1	88 46.8	17030	−0 12	0.3544	40 59[c]
21	Chubitang	27 24.9	88 52.5	13190	......	0.3587	40 12[c]
22	Yatung	27 29.0	88 54.2	9780	−0 30	0.3602	40 06
23	Gotsa	27 34.2	89 01.4	12340	−0 26	0.3586	40 26[c]
24	Phari	27 43.1	89 09.5	14370	−0 17	0.3579	40 35
25	Tuna	27 56.8	89 13.5	14900	−0 21	0.3560	41 09
26	Dochen	28 07.5	89 18.0	14860	−0 19	0.3558	41 05
27	Kalashar	28 16.2	89 22.8	14830	−0 25	0.3556	41 24
28	Samada	28 24.3	89 33.4	14470	−0 27	0.3548	41 44
29	Kangmar	28 33.7	89 40.7	14110	−0 15	0.3549	41 50
30	Sakang	28 43.5	89 38.9	13520	−0 28	0.3547	42 05
31	Gyantse	28 54.6	89 36.0	13290	−0 25	0.3542	42 31
32	Gobshi	28 50.1	89 50.9	13980	......	0.3539	42 21
33	Ralung	28 48.9	90 02.3	14760	−0 22	0.3541	42 23
34	Pede Dzong	29 07.5	90 27.0	14830	−0 20	0.3533	42 46
35	Kampadombo	29 16.1	90 38.0	12170	−0 22	0.3557	42 49
36	Shushul	29 21.3	90 44.2	12170	−0 31	0.3570	42 59[c]
37	Lhasa	29 39.1	91 07.5	12240	−0 26	0.3503	43 36
38	Cche	29 38.6	91 13.2	12400	......	0.3531	43 38[c]
39	Nyenga	29 38.9	91 21.9	12630	−0 24	0.3490	43 42
40	Samye Gompa	29 19.6	91 30.5	11880	−0 50	0.3463	43 52
41	Tsetang	29 15.4	91 46.3	11810	−0 41	0.3501	43 25
42	Potrang	29 07.2	91 50.0	12170	−0 39	0 3546	42 38
43	Tsangchung Lingka	29 15.4	91 39.8	12110	−0 39	0.3528	43 15[c]
44	Tsongdü	29 14.5	91 24.8	12040	−0 10	0.3552	43 11
45	Chitesho Dzong	29 17.1	91 07.4	12070	−1 50	0.3527	43 15
46	Ramedh	29 17.2	91 00.3	12140	−1 00	0.3529	43 19[c]
47	Kongka Dzong	29 15.4	90 47.7	12270	.....	0.3559	43 09
48	Chutsenkar	29 08.0	90 02.0	13880	−0 27	0.3528	42 48
49	Rinpung Dzong	29 15.9	89 44.9	12860	−0 18	0.3525	42 36
50	Niamo	29 21.2	89 27.1	12700	−0 17	0.3518	43 09
51	Nubri	29 19.7	89 15.9	12730	−0 51	0.3529	43 23
52	Shigatse	29 17.3	88 53.3	12800	−0 15	0.3523	43 08
53	Chola	29 23.9	89 02.2	12860	−0 20	0.3483	43 42
54	Penam Dzong	29 10.8	89 11.4	13190	+0 07	0.3577	44 01
55	Takse	29 05.0	89 28.0	13120	−0 24	0.3533	43 01

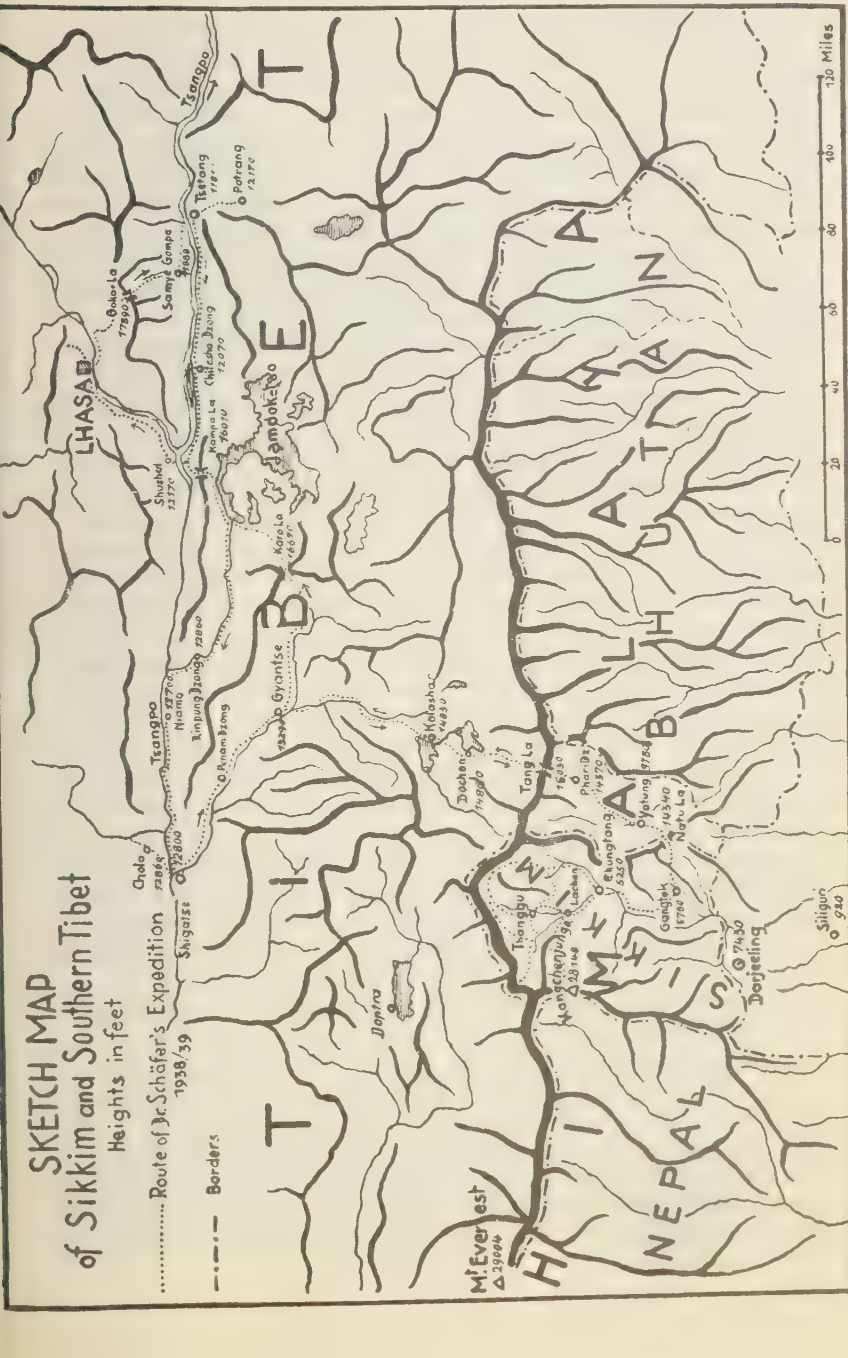

FIG 1—CHART ACCOMPANYING PRELIMINARY REPORT ON MAGNETIC RESULTS IN SIKKIM AND SOUTHERN TIBET BY K. WIENERT

of Berlin-Friedenau. It had a large temperature-coefficient, which was deduced from the differences of the evening and morning observations at the same place. The temperature-changes were as much as 25°C.

The scale-value was determined from deflections with Magnet I of the magnetometer, the magnetic moment being calculated from the observations of H. It only changed once, when the servant, who used to carry the instrument, fell from a horse. The mean error of a single observation was derived from observations around Lhasa where numerous stations were repeated as many as five times; it was found to be $\pm 25\ \gamma$. The survey of the environs of Lhasa also proved that the balance may be expected to keep a constant base-value within a range of 40 γ for a period of two months. This, however, does not exclude the possibility that greater changes occurred during the expedition. The values of Z which were obtained in Sikkim are very reliable because it was possible to make up a network and thus to determine the changes of the base-value wherever they happened. Far worse were things in Tibet. Along the route of the expedition which represented the backbone of the survey, stations generally could be measured only once. Two sections of the route were measured twice, namely, Gangtok to Yatung to Gyantse with a final difference of 120 γ, and Pede Dzong to Kampadombo with a final difference of 80 γ. Two sections could be controlled because of return to the beginning of the section. To one section belonged the stations Kampadombo, Lhasa, Samye Gompa, Chitesho Dzong, and Kampadombo (final difference 140 γ). The other section begun at Gyantse, comprised the stations Ralung, Pede Dzong, Rinpung Dzong, Shigatse, and ended at Gyantse, where the final difference was found to be 50 γ. The final differences were distributed over the section in question. However, the accuracy of local investigations is much better, since it was possible to return to the base-station very often, and thus to control the base-values of the instrument.

The observations were very much affected by the large temperature-changes which were sometimes higher than 30°C during one day. It is not possible to reduce the radiation-effect of the Sun except by a better thermic isolation which would make the instrument clumsy and less suitable for use on expeditions.

The normal-field formula of Z was derived from 120 of the observed 634 stations as follows

$$\begin{array}{llll} \text{Normal } Z = & 31644\ \gamma + & 1356\ \gamma(\Delta\varphi) & +86\ \gamma(\Delta\lambda) \\ & \pm 15\ \gamma & \pm 33\ \gamma & \pm 24\ \gamma \end{array}$$

(8) *Local anomalies in vertical intensity*—Because of limitations of space, only a short description of the results of the Z-measurements can be given. A full report will be published later. A comparison of the values derived from the normal-field formula with those actually measured reveals

the individual features of the different regions. A chart of isanomals was compiled, from which the following facts were derived.

Sikkim is slightly disturbed. At its southern border the observed values are higher than those given by the normal field. To the north of Lachen there is an anomaly which is well surveyed. It ranges from $+400$ to $-380\,\gamma$. The theoretical investigation is rather difficult as the altitudes vary from 8800 to 17,000 feet. As a vertical gradient was not deduced, it is hard to reduce all stations to the same level. Haalk's diagram-method for the location of the disturbing structure was used. This anomaly seems to be caused by a solid and rather large body of crystalline rocks of moderate susceptibility. The surface of the structure is about 10,000 feet below the ground. At the northern border of Sikkim there are indications of an anomaly in the upper Lhonak valley (No. 9, Goma). The region around Gayokang gives too small values compared with the normal field. As the south of Sikkim is positively disturbed (altitude 1300 feet) whilst the north of it (16,000 feet) is negative, it is possible that these differences originate at least partly from a vertical gradient which is not taken into account in the computation of the normal field.

In the mountains between Lachen Chu and Lachung Chu there are [illegible] stations which deviate from the normal field by about $+300\,\gamma$. Possibly basaltic rocks (volcanic veins?) are the cause of these anomalies of very small extension. In this region post-volcanic phenomena (hot springs) are observed. On the way from Gangtok to Yatung there are indications of small anomalies with maximum values of $+210\,\gamma$. Negative anomalies were found between Dochen and Kalashar and at Samada with minima of -350 and $-270\,\gamma$, respectively. South of Sakang a positive anomaly of $+390\,\gamma$ was found. The area between Gyantse and Penam Dzong is covered by an anomaly of nearly regional character. Its maximum is $+350\,\gamma$. Between Shigatse and Penam Dzong (29° 13′ north, 89° 05′ east) an anomaly with a minimum of $-420\,\gamma$ was surveyed. A small negative anomaly was found southeast of Pede Dzong, and a positive one at Tsatang (29° 08′ north, 90° 15′ east). The latter reaches a maximum amount of $+680\,\gamma$ and has an extension of only 1200 feet. It is rather certain that this anomaly is caused by material of high susceptibility lying near the surface.

The Tsangpo Valley is a region in which large anomalies are very frequent. Three different types are to be found. The first type varies between maximum values of $+400$ to $+500\,\gamma$. The diameter of the zero isanomal line ranges from 5 to 15 miles. The maximum is rather flat. It is quite similar to the anomalies found north of Lachen and near Sakang. Anomalies of this type were found at Lhasa, Nubri, and between Chaksam (south of Shushul, on the southern shore of the Tsangpo) and Tsetang. The maxima of the second type vary between $+1000$ and $+2600\,\gamma$. The extension is the same as that of the first type. Near the zero-line the values increase slowly

but increase quickly near the maximum. A minimum was only observed near Chaksam, and reached an amount of $-250\,\gamma$. This type is represented by the anomalies of Chola (northeast of Shigatse on the northern bank of the Tsangpo), near Niamo, at Rinpung Dzong, and at Chaksam. The third type is an anomaly of very small extension. It is only one mile from east to west and about 2.5 miles from north to south. The maximum and minimum were found to be $+1270$ and $-870\,\gamma$, respectively. It is represented by a single anomaly, namely that of Tsetang.

The anomalies of the first type seem to be caused by crystalline rocks of moderate susceptibility, as was found in the anomaly of Lachen. The upper surface of the disturbing structure is about 6500 to 15,000 feet below the ground. The cause of the third type is to be sought in a basaltic vein of extremely high susceptibility; its depth is less than 300 feet.

A close investigation of the second type, especially that of its most characteristic representative, the anomaly of Chaksam, revealed that it must be a combination of the first and third type. The observed values indicate that they are composed of effects of large structures lying in a depth of 6500 to 15,000 feet, and of those of small extension which are very near the surface. The most simple explanation is that the disturbing structures consist of sub-volcanic massives from which veins, usually one but two in the anomaly near Niamo and at least three in the Chaksam anomaly, go up close to the ground or even reach it. Since anomalies of this type are only to be found in the Tsangpo Valley it may be concluded that the valley is a tectonic line most probably of the character of the Upper Rhine between Schaffhausen and Mainz, the bottom of the valley being dislocated by downward movement and not, as usually assumed, worked out by erosion. The veins were pressed up through the dislocation-fissures.

A large negative anomaly covers the area between Dechen Dzong (northwest of Gokar La) and Samye Gompa for which a proper explanation can not yet be given. Its minimum reaches nearly $-1000\,\gamma$.

It is to be deplored that no further investigations could be made north of the Tsangpo Valley. The material obtained does not permit much to be said about the magnetic character of the Trans-Himalaya or to base on it conclusions on differences of the Himalaya and Trans-Himalaya.

Most of the anomalies are worthy of closer reinvestigation. A careful survey that covers the whole area should be made to reveal further facts on its geology. Before further investigations in the Himalaya are commenced, a magnetic survey of the Central Alps should be made. The Alps are well known with regard to geology. A comparison of the magnetic phenomena of the Alps with those of the Himalaya would yield useful conclusions on the geology of the latter.

(9) *Final remarks*—In spelling the names of places the English transcription as given in the map of "India and Adjacent Countries" (scale

1:253,440) was followed. From this map also the geographical coordinates of stations 1 to 22, 38, and 48 were read. The name of Yabuk was taken from Marcel Kurz's map (1:100,000) of the Central Himalaya. The following stations are recommended as repeat-stations: Gangtok; Chungtang; Gayokang; Phari; Kalashar; Gyantse; Lhasa; and Shigatse. These stations are not, or are only slightly, disturbed by local anomalies. Moreover, careful descriptions and sketches of the places are available, and the magnetic elements have been determined at least twice.

It is to be desired for further expeditions that a station be installed close to the area of the expedition to record the magnetic elements. In case this is not possible, H and Z should be observed by field-balances every 15 or 20 minutes when performing absolute measurements. The investigation of local anomalies should not only consist of observations of Z; it will not take much more time to observe H and D-measurements should be made if the Sun is not too high. The Askania Werke have issued a slit-and-thread device for the tripod of the field-balance, with which D can be determined with an accuracy of about $5'$. These additional observations would permit analyses of anomalies much better than with vertical-intensity alone.

The equipment should consist of a field-magnetometer of usual type together with three quartz torsion magnetometers (la Cour), or a sine-galvanometer (when possible as supplement to the magnetometer) which is liable to give good results in a short time, an earth-inductor, at least one field-balance for Z but preferably two, which would permit omitting dip-observations at every second absolute station and recording of vertical-intensity variations by a second observer for local investigations, and a field-balance for H.

The expedition has been generously supported by the "Deutsche Forschungsgemeinschaft" with instruments and money.

References

[1] Robitzsch, Ausfuehrliche barometrische Reduktions- und Hoehentafeln, Leipzig, 1939.

[2] Bock, Praxis der magnetischen Messungen, Berlin, 1942.

[3] Wienert, Erdmagnetische Arbeiten in Tibet, Die Askania-Warte, Nr. 35.

Regensburg, Germany, September 22, 1947

LETTERS TO EDITOR

(See also pages 448, 451, and 495)

CHELTENHAM *K*-INDICES FOR JULY TO SEPTEMBER, 1947

In continuation of data on geomagnetic activity in the last issue of the Journal [52, 403-409 (1947)], the *K*-indices for July to September, 1947, are given in Table 1 as determined from the records at the Cheltenham Magnetic Observatory.

Table 1 - Three-hour-range indices (K)

Cheltenham Magnetic Observatory, June-September, 1947

Gr.	July 1947		August 1947		September 1947	
day	Values K	Sum	Values K	Sum	Values K	Sum
1	3 3 2 2 2 3 2 3	20	4 2 4 3 2 3 4 3	25	3 2 2 2 1 1 3 2	16
2	3 5 3 2 3 2 2 3	23	2 2 3 3 3 3 3 3	22	2 1 2 1 2 2 2 5	17
3	2 2 3 2 1 2 2 2	16	3 1 3 2 2 2 3 3	19	4 4 7 6 5 5 4 4	39
4	0 1 1 2 0 1 1 1	7	3 3 3 3 2 1 2 3	20	4 5 5 4 4 3 4 2	31
5	2 1 1 1 0 0 1 2	8	3 2 2 2 2 1 2 2	16	3 2 3 2 3 2 3 4	22
6	3 2 2 2 2 2 3 2	18	2 3 2 3 3 2 3 3	21	4 2 3 2 3 3 3 3	23
7	3 2 1 0 2 2 2 3	15	3 3 2 1 1 2 3 2	17	4 4 4 3 3 4 5 4	31
8	2 3 2 2 2 3 4 4	22	3 2 2 1 2 2 1 1	14	4 3 4 2 3 2 1 1	20
9	3 2 2 2 1 1 4 4	19	1 3 2 1 0 1 2 4	14	2 0 1 0 1 0 2 2	8
10	4 3 2 3 2 2 3 3	22	2 3 2 2 2 1 1 2	15	1 1 0 0 0 1 1 2	6
11	3 2 2 2 3 2 2 5	21	2 3 2 2 3 2 2 3	19	1 0 1 2 2 3 3 3	15
12	3 3 1 2 2 2 3 3	19	4 5 5 4 3 2 3 3	29	3 3 3 3 1 1 2 4	20
13	3 3 2 2 2 2 2 3	19	3 2 4 3 3 4 5 5	29	6 5 5 5 5 2 3 5	36
14	2 0 0 0 1 2 3 3	11	4 3 2 2 2 2 2 2	19	3 5 6 5 5 4 4 4	36
15	2 4 1 0 1 2 2 2	14	1 2 3 5 4 5 5 7	32	5 5 4 4 4 4 4 4	34
16	3 3 0 0 0 0 1 1	8	6 4 3 4 5 4 5 4	35	3 3 4 1 1 2 3 5	22
17	1 0 0 2 1 4 7 7	22	4 5 6 6 4 4 5 4	38	4 5 5 4 3 3 3 5	32
18	7 4 4 5 5 5 4 4	38	6 4 4 5 4 3 4 5	35	6 3 4 3 4 3 3 5	31
19	6 4 3 4 3 3 3 2	28	4 4 4 5 4 5 4 5	35	4 4 4 3 2 3 2 5	27
20	3 5 4 3 4 5 3 3	30	5 4 4 4 4 4 4 4	33	4 3 3 3 2 3 1 3	22
21	2 3 3 3 2 2 3 2	20	5 5 4 4 4 3 4 4	33	3 4 4 4 3 1 2 3	24
22	2 2 2 3 3 2 4 4	22	3 4 5 9 5 6 5 4	41	1 4 5 4 4 3 4 4	29
23	3 4 3 4 3 3 5 5	30	6 5 5 3 5 4 4 3	35	4 6 5 5 5 1 2 3	31
24	2 4 3 2 2 2 3 3	21	3 4 5 3 3 2 3 3	26	3 4 5 5 5 5 6 6	39
25	3 3 3 3 4 4 3 3	26	5 5 5 5 3 3 3 3	32	8 6 7 5 4 4 4 4	42
26	4 4 5 3 3 2 3 3	27	2 3 4 4 2 1 1 2	19	5 4 1 1 2 2 3 3	21
27	2 4 4 3 3 3 3 3	25	3 3 5 4 2 1 1 1	20	3 3 2 1 3 2 2 3	19
28	3 2 3 3 1 2 2 3	19	2 2 2 1 2 2 2 4	17	3 1 1 5 2 2 3 2	17
29	3 4 3 2 2 2 2 0	18	3 2 2 2 2 2 3 3	19	2 3 2 2 1 1 2 3	16
30	1 2 3 1 2 2 2 2	15	3 3 2 1 1 1 1 2	14	2 2 0 1 0 1 4 3	13
31	2 2 2 1 2 2 3 3	17	1 2 1 2 4 4 4 4	22		

Cheltenham Magnetic Observatory,
Cheltenham, Maryland, October 30, 1947

William E. Wiles,
Observer-in-Charge

SUMMARY OF THE YEAR'S WORK, TO JUNE 30, 1947, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON

By M. A. Tuve and H. D. Harradon

This first year of post-war operations marks a major change in the activities of the Department, with the completion of the observatory and field-party work of the world magnetic survey.

Much of our effort in the past has been concerned with obtaining and interpreting large numbers of observations on the magnetic and electric conditions of the Earth. During the first two decades after 1904 the Department was occupied with a world survey of the Earth's magnetic and electric fields, using the *Galilee* and the *Carnegie* to cruise all the oceanic areas, and organizing parties on land to occupy thousands of stations scattered over every continent and in the Arctic and Antarctic. At the end of World War I plans were inaugurated for establishing a number of observatories, to be located at the special sites needed to round out at least a rough approximation of a world coverage, in order to make systematic studies of the variations of the Earth's magnetic and electric fields and other related quantities, particularly in relation to solar effects and magnetic storms. Only two of the list of projected observing stations were established, one at Huancayo, Peru, and the other at Watheroo, Western Australia, but these were fortunately the most vital locations needed for a reasonable world picture. Largely by reason of the extensive and accurate observations made at these stations, comprehensive treatments of the daily, yearly, and sunspot-cycle effects on the electrical currents in the upper atmosphere and in the Earth's crust have been made during the past 20 years, and many new facts brought out, especially in relation to magnetic storms and other aspects of solar activity. The addition of new analytical procedures based on the technique of observing echoes from radio-pulse transmitters, first demonstrated by the Department's laboratory group in 1925, gave quantitative information of great significance, and this work was expanded into world-wide activities of the Armed Services of many nations and all agencies concerned with radio communication. Numerous other cooperative activities, concerned with seismology, meteorology, cosmic and auroral rays, and other solar disturbances have fitted naturally into this program. The original planning for this observatory-program contemplated the integration of our stations into the scientific life of their local areas, and the expected transfer of our activities to local sponsors at the end of 25 years.

A survey of the situation at the end of World War II disclosed two things. First, our two observatories had achieved world recognition as

stations of paramount importance in the uneven world distribution of observing stations, and were recognized as such by the governments and scientific agencies in their areas. Second, our own estimate of the status of the problems for which they were established indicated that the most striking puzzles connected with the Earth's magnetic and electric properties might be approached more fruitfully by attempting geophysical experiments of relatively limited duration than by expending most of the efforts of a small group such as ours on a program of continued observations. Fortunately the governments of all nations are now much more alive to the importance of scientific activities, and the collection of geophysical data over long periods is widely accepted as an appropriate activity for a governmental scientific bureau. Accordingly, a decision was made to transfer by gift the entire establishment of each observatory to the governments of Peru and Australia, respectively. This proposal was gratefully accepted by both governments and arrangements were made for the transfers to be effective July 1, 1947.

In rounding out our activities toward the completion of this matured program the publication of 16 large volumes of data and interpretation was undertaken. Much of the work of computation and study had been done previously, and on July 1, 1947, only minor editorial and assembly work remained to be completed on the last five volumes.

The Department now turns to a new emphasis on laboratory and experimental work. Two outstanding problems remain unsolved by our past program, namely, (1) the origin or cause of the main part (95 per cent) of the Earth's very large magnetic moment, and (2) the maintenance of the Earth's electric charge in spite of the constant current of many thousands of amperes from the air to the surface of the Earth. There are other striking problems relating to the physics of the Earth and there is ample precedent for our confidence that they are not disconnected, and that initiative in attempting new experiments and making fresh approaches will yield results of unexpectedly wide significance.

Most of our studies in the past have been concerned with descriptions of phenomena related to these puzzles, such as the small daily, annual, secular, and storm variations of this large and unexplained magnetic field, the contributions of the ionosphere and earth-currents to these magnetic variations, and studies of the behavior of ions and attachment particles in the air which participate in this puzzling air-earth current. Because these problems of magnetism and electricity embrace the entire solid Earth and the atmosphere, and relate directly to some of the great fundamental questions concerning the structure of matter, there also have been vigorous thrusts in several other fields of physics, including studies in high voltages and nuclear physics.

Plans for cooperative activities in which other agencies play a larger part than the Department, in magnetic work, in exploratory geophysics, in

laboratory physics, and in biophysics, characterize the entire program of the Department for the next few years as the staff now views it. For any one subject or project only a small group will be concerned here in the Department (often not more than two or three), and members of other organizations will participate as importantly in our projects as ourselves. True research, however—creative research—is always done in small groups, rarely exceeding five or seven individuals. Hence this separation of the Department's staff into very small discrete groups, with reasonable fluidity for shifts between groups, is regarded as both realistic and healthy.

The activities of the Department and the interests of the research staff divide naturally among three broad areas: (*a*) Statistical and analytical geophysics, including observatory results; (*b*) exploratory geophysics; and (*c*) laboratory physics and biophysics. In the past the main emphasis of the Department has been in the first area, but it has been agreed, with the Department's observatory program already carried through two complete sunspot-cycles, that a general shift of emphasis will now occur away from this first area and toward the other two.

The Department's activities thus move toward those of a physics department with special emphasis on geophysical experiments, but making intensive use of the techniques and ideas of modern physics. The program in biophysics, which has evolved out of our pioneering activities in nuclear physics and on the magnetic properties of the primary particles of matter, rests on a similar foundation of modern physics, but with special interest in the fundamental physical properties of living matter, as a joint activity with the many biological groups in the Washington area.

A surprising discovery was made during the year in the cosmic-ray program. Long-continued observations of cosmic-ray intensity have been made at various stations scattered over the Earth during the past 12 years as a part of the Department's program. Variations of about one per cent due to atmospheric changes and decreases of a few per cent caused by the increased magnetic moment of the Earth following magnetic storms have been regularly noted, but a pronounced solar flare and radio blackout on July 25, 1946, was accompanied by a large *increase* in cosmic-ray intensity at all stations except at the equator, simultaneous with the flare and radio disturbance and lasting for several hours. A magnetic storm and its effects occurred as usual about a day later. The observations cannot be explained by the known change in the Earth's magnetic moment due to ionization by ultraviolet light. It is difficult to see how the magnetic moment of the Sun, usually assumed as the explanation of the cut-off of low-energy cosmic rays, can have been sufficiently altered by the flare-effects to permit a "beam" of cosmic rays to pass by. The only evident alternative is that the additional cosmic rays were produced by an accelerating action associated with the flare at or near the Sun, possibly due to a local rate of change of magnetic field, as in a betatron accelerator. The origin of cosmic rays is so mysterious

that a hint of this kind, associated with our nearest star and hence observable in some detail, with patience, is of the greatest interest. Search of the records revealed two similar occurrences in 1942, or a total of three in ten years.

The measurements by Babcock of the Mount Wilson Observatory on the magnetic fields of the Sun and of "Virginis-I" have stimulated the British physicist, Blackett, to speculate again on the possibility that the Earth's magnetic field represents a fundamental phenomenon in which the magnetic field is dependent upon the mass and angular momentum of the body. There are other explanations of the Earth's field which depend upon complex internal phenomena in the core of the Earth. To distinguish between these theories is of fundamental importance to geophysics and to physics as well.

The most fundamental lack is that of quantitative data on the behavior of the Earth's field with time. Measurements of the faint residual magnetization of the annual layers of silt deposited by retreating glaciers at the end of the last Ice Age, about 25,000 years ago, were resumed during the year with results of striking interest. Just prior to the war these experiments had indicated that the deviation of the compass-direction from true north had varied in a fashion similar to the changes observed during the past 350 years. Numerous tests this year have given strong evidence for the stability of this residual magnetization and hence the reliability of these measurements as a measure of the ancient compass-direction. In addition, new procedures have been developed, involving the re-deposit out of a water bath in a magnetic field of the silt from single layers, which give a tentative measure of the *intensity* of the Earth's magnetic field during that distant epoch. A preliminary determination of the intensity of the Earth's field at the time of the last glaciation has now been made from clays collected at Bradford, Vermont. This measurement indicates that the Earth's field has been unchanged in intensity for the last 30,000 years to within the accuracy of the measurement. The material used was shown to be able to carry the imprint of a field 50 times less or greater than the present value. The direction as well has remained substantially constant. The clays were collected in New England and were dated by the fine work of Dr. Ernst Antevs, former Research Associate of the Carnegie Institution of Washington. The interpretation of the polarization of the clays was obtained only after long and tedious work in the laboratory using the methods of modern physics. It is expected that the measurement of other clays will make it possible to extend this time-scale to millions of years and thus to provide the quantitative data necessary to distinguish between conflicting theories. The experiments and observations are being extended, and some tests are under way with sedimentary rocks. There is a special satisfaction in measuring a thing as subtle as the Earth's magnetic field as it existed 25,000 years ago. If these studies can be successfully extended to rocks and hence to

cover a vastly greater period of time, important limits will be set on theories of the Earth's main field, a stupendous magnetic phenomenon which remains both a riddle and a challenge.

An interesting series of experiments using artificially radioactive tracer substances was carried out during the year by the cyclotron staff of the Department and their many colleagues in biology and medicine in the Washington area. Radioactive samples were also supplied to a large number of investigators in many parts of the world, since the tracer elements produced in the atomic-energy piles are not available for foreign distribution. The work here has been concerned primarily with studies of differential permeability and exchange through various membranes and cell walls in animals and in man. Although many of the observations, especially those related to the heavy metal compounds which were the war assignment of our cyclotron, are of immediate interest to medical men our experiments and plans are directed toward the fundamental physical properties of living systems.

The structure of the atomic nucleus offers another major problem. There is ample evidence that the nuclear constituents (protons, neutrons, and possibly alpha particles) are organized in some systematic way. This is shown in the distribution of the stable elements, the atomic masses, and many of their other properties such as spin (angular momentum) and magnetic moment. However, the system is not known. The quantum theory used with such great success in explaining the outer structure of the atom has great difficulty in the nucleus, first, because the forces are not known and second, because the approximations used in the electronic structure are not possible in the nucleus where many particles are interacting. In view of these difficulties a model of the nucleus based on similarity to a liquid drop has been found useful in some cases. However, this gives only a rough approximation and fails to predict the periodicities of nuclear structure. Measurement of the angular distribution of the particles emitted in nuclear reactions gives a critical test of the theory of nuclear structure. During the past year the electrostatic generators have been used to study the light elements and the cyclotron for the heavy ones. The results obtained show that even the light elements (lithium and oxygen) are not simple in structure. Neither is the behavior of heavier elements (aluminum, copper, and gold) predictable from the liquid-drop model.

Observatory work.—The geomagnetic, ionospheric, seismic, and meteorological programs were maintained at the Huancayo Magnetic Observatory. Fast-run magnetic recording with the la Cour magnetograph and spectroheloscope observations of the Sun's activity with the Hale instrument were discontinued on July 31, 1946, and the atmospheric-electric and earth-current recorders were discontinued at the end of 1946. The weekly radiotelegraphic reports of K-indices were terminated at the same time. A complete reduction and tabulation of the final hourly values of all three mag-

netic elements beginning with September, 1946, was undertaken at the Observatory instead of at the Washington office.

At the Watheroo Magnetic Observatory the geophysical program of observation and recording of geomagnetic and ionospheric data was continued throughout the year. Recordings of the atmospheric-electric elements were discontinued at the end of 1946 after a continuous series of 24 years had been obtained. The earth-current recorder remained in operation but the values were not tabulated. Current ionospheric data were supplied, as in previous years, to the Radio Research Board at Sydney and the Central Radio Propagation Laboratory, at Washington. The Observatory was transferred to the Australian Government on July 1, 1947, and continues to operate under the auspices of the Bureau of Mineral Resources of the Department of Supply and Shipping.

Primary standard—For many years the Carnegie Institution of Washington has played a leading international role in developing and maintaining the magnetic standards of the world, both by the construction of many of the magnetometers used in field-measurements and by comparisons of observatory-standards. The last primary standards built are now nearly 30 years old. In anticipation of the grave need of maintaining the international standards and of obtaining international agreement on the value of the gamma, the previous director, J. A. Fleming, initiated the construction of a new primary standard of great accuracy in 1934. This standard has now been completed. It permits, for the first time, the measurement of any component of the Earth's magnetic vector, although it is principally designed for the measurement of H, Z, D, and I. Its constant is determined by the mutual inductance between a primary coil and a rotating secondary coil. The absolute value of this coil-constant is known to three parts in a million. It is expected that this coil will be used by the United States Coast and Geodetic Survey and that when its operation is satisfactory, it will provide a firm basis for the adoption of a standard value for the gamma.

Experimental and analytical geophysics—The new exploratory approach of the Department to the geophysics of the solid part of the Earth is divided into two main parts: (1) To determine its physical history by reading the record of this history from the evidence of the crust itself; (2) to penetrate as deeply as possible beneath the surface to determine its internal constitution. Three main problems are now presented: The first concerns the magnetic history of the Earth; the second, concerns the strength and structure of the Earth's crust to great depths; and the third concerns the conductivity and the temperature of the crust to great depths.

In connection with the study of the upper atmosphere the following projects have been initiated: (1) Radio-frequency noise from the Sun. (2) Thunderstorm project: This program is directed toward an answer to the fundamental question: Why does the Earth have a negative charge and how is it maintained? Measurements of atmospheric conductivity and

potential-gradient made during airplane flights above representative thunderclouds may prove or disprove the theory that electrical current-flow from the ionosphere into thunderstorms is sufficient to maintain the Earth's negative charge. The instruments have been completed and preparations are made for construction of additional units as required. (3) Fine structure of the ionosphere: Preparations are made to complete the developmental work on the panoramic recorder and to obtain a representative series of high-speed motion-picture recordings of ionospheric disturbances such as radio fadeout, sporadic *E*, magnetic-storm effects, and similar phenomena. Such information should make available new data as a basis for the interpretation and understanding of many physical processes in the Earth's outer atmosphere. (4) Upper-air rocket experiments offering new opportunities for direct measurements in the region 100 km or more above the Earth have been opened by the experimental firing of the V-2 and other rockets by the Armed Services of the United States. Among the experiments, closely related to the interests of the Department, one concerns the direct observation of the large electrical currents which circulate in the upper atmosphere and cause magnetic variations at the surface of the Earth. Other related projects which may be undertaken include: (*a*) Measurement of the Earth's magnetic field in the ionosphere by radio methods; and (*b*) experimental measurements in the lower atmosphere; (*c*) examination of the implications of the discovery of abnormal increases in world-wide cosmic-ray increases during a few great isolated solar eruptions.

Analysis—Extensive new descriptions of the Earth's main field and its secular change, 1905-1945, mainly in more accurate mapped form, were unsuccessfully compared with those of other geophysical phenomena manifested in the Earth's crust. There were, however, aspects of these comparisons that seem worthy of further examination. For example, there seems to be some apparent correlation with general features of stress-distributions with the Earth's crust, deduced by Vening-Meinesz in attempting explanation of faulting and topography of the Earth's surface, in turn related to other crustal phenomena. An examination of this possibility is being continued.

A spherical harmonic analysis of the Earth's main field for 1945.0 indicated that the fraction of the dipole component of the main field of external origin was less than one per cent of the observed surface field, and thus considerably less than indicated by previous analyses. Examination of the analyses of secular change at four epochs, a decade apart, indicated a rather steady decrease of about 20 gammas per annum in the dipole component, though the most recent value, that for epoch 1942.5, is considerably less, and may indicate that the dipole component of the main field may at the present time be diminishing at a rate less rapid than during the previous century.

An external and non-potential part of the main field, and variation of the vertical component of curl of field, postulated by the Schrödinger unitary field theory could not be detected from analysis and comparisons with the new and more accurate descriptions of the geomagnetic field. This result is contrary to Schrödinger's findings based on Schmidt's analysis for 1885.

The new analysis gave the coordinates for 1945.0 of the north geomagnetic pole as (78°.6 north, 289°.9 east), and for the south geomagnetic pole (78°.6 south, 109°.9 east); these results differ from those of Bauer for 1922 by only 0°.1 in latitude and 1°.1 in longitude.

Calculations of the main field and its secular change were completed for various levels within and beyond the Earth's atmosphere, thus providing useful data for studies of electrical phenomena of the upper atmosphere. Vertical gradients of the main field and its secular change were calculated for the Earth's surface, but attempts to correlate these with other geophysical phenomena were unsuccessful.

Current-functions which could produce the main field and secular change calculated for flow of currents on a thin spherical shell at depth 3000 km were found to be highly complex. This renders it unlikely that a major part of the main field or secular change could originate below the surface of the Earth's central core, though it might be admissible to have flow of current very near the surface of this core as suggested recently by Elsasser.

The unexplained average augmentation in earth-currents during January, as compared with December and February, found by Rooney for Tucson, has likewise been found in 12-year means for the solar daily magnetic variation, at stations throughout the Western Hemisphere, but not in the Eastern Hemisphere.

Publication of observatory and field observations—Early in the report year it was decided that the results of researches in terrestrial magnetism, ionospherics, cosmic rays, atmospheric electricity, and earth-currents would be presented in tabular form in 17 volumes totaling approximately 10,000 pages. During the year six volumes of results have been completed, two representing the magnetic results from Watheroo for the years 1919 through 1944, a volume descriptive of the Earth's main magnetic field and its secular change for the period 1905 to 1945, a volume presenting the Tucson Observatory earth-current results for the period 1932 to 1942, the land and ocean magnetic results for the period 1927 to 1944, and ionospheric results from College, Alaska, for the period 1941 to 1946, a total of 3163 pages. Manuscripts of eight additional volumes have been prepared, covering work on geomagnetism, the ionosphere, earth-currents, and atmospheric electricity at various observatories, including Watheroo and Huancayo.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington 15, D. C., November 4, 1947

REPORT OF TEMPORARY SUB-COMMISSION* ON LIQUIDATION OF AGENDA OF THE INTERNATIONAL COMMISSION FOR THE POLAR YEAR 1932-1933

By J. A. Fleming, J. Keränen, J. M. Stagg, and A. Thomson

Introduction

The realization of the Second Polar Year in 1932-1933, as a truly international project, is a monument to the enthusiasm and indefatigability of the late Dr. D. la Cour and to the support generously provided by the Danish Meteorological Institute. From it have already resulted many valuable contributions to knowledge of polar geophysics in numerous publications and in completed or partially completed manuscripts. There remains much material not yet fully compiled or discussed. It would be peculiarly unfortunate if the potentialities for increased understanding of polar geophysics resulting from this great project, in which so many nations and men took selfless part at great cost, were not fully analysed and published. The past ten years have demonstrated that progress and future human welfare depend upon more solid knowledge of natural phenomena in the Arctic and Antarctic.

*Recommendations** on liquidation of agenda*

(1) *Terminal date*—Limitation of period for completion of compilations, analyses, discussions, and publication is essential. It is recommended that a terminal date be set as December 31, 1950.

(2*a*) *Continuance of temporary Sub-Commission*—It is recommended that the Sub-Commission be continued in charge until December 31, 1950, and that its personnel be added to by the appointment of (*a*) Dr. Helge Petersen, Director of the Danish Meteorological Institute, and (*b*) Dr. Harald U. Sverdrup, who is to become Director of the National Institute for Polar Research of Norway early in 1948, with the understanding that the total membership be limited to six and that replacements because of resignation or death be made by the Sub-Commission with the approval of the President of the International Meteorological Committee.

(2*b*) The Sub-Commission requests authority to (*a*) co-opt services of scientific men as it deems desirable to effect completion of agenda on or before the terminal date, (*b*) approve expenditures of any funds now available or hereafter made available for necessary services and costs of publication, (*c*) set up a suitable Central Bureau and repository of all records, materials, and publications of the Polar Year 1932-1933 and of funds, and

*J. A. Fleming (Chairman), J. Keränen, J. M. Stagg, and A. Thomson, appointed, per resolution adopted by the International Meteorological Committee at Paris, July, 1946, by President N. K. Johnson in letter dated November 15, 1946.

**Following reading and discussion of this report at the Directors' Conference of the International Meteorological Organization in Washington on October 8, 1947, the recommendations made were all adopted.

(*d*) appoint, with the approval of the director of the organization designated to house the Central Bureau, a part-time or full-time paid Executive Officer whose duties and responsibilities shall be set by the Sub-Commission. (Note: The Sub-Commission hopes that the Danish Meteorological Institute, which has taken so prominent a part in the Polar Year 1932-1933, may be willing to continue provision of facilities for the Central Bureau.)

(3*a*) *Funds and property*—Funds presently available for liquidation of the agenda are deposited with the Danish Meteorological Institute.

(3*b*) Unfortunately the Rockefeller Foundation reverted, some years ago, the balance of $12,000 remaining in its original grant of $15,000. It is recommended that a formal application* to the Rockefeller Foundation by the International Meteorological Organization be authorized for a final grant of $12,000, or as much thereof as necessary, to terminate December 31, 1950, setting forth the importance and need of that amount to complete the work originally contemplated by the original grant and now of urgent importance to scientific progress and human economic welfare in polar geophysics.

(3*c*) The Sub-Commission believes that further financial aid may be appropriately requested from (*a*) the International Associations of Meteorology and of Terrestrial Magnetism and Electricity both of which are concerned with investigations of natural phenomena in the Arctic and Antarctic and who have previously supported the program of the Polar Year 1932-1933, (*b*) possibly the Division of Natural Sciences of the United Nations Educational, Scientific, and Cultural Organization, (*c*) the Arctic Institute of North America, and (*d*) the International Meteorological Organization.

(3*d*) Preparation of a complete inventory is recommended of all instruments and property acquired by the Polar Year Commission of 1932-1933 showing (*a*) original purchases and (*b*) present distribution by gift or loan or in storage, as also authority to dispose of all in accordance with the now urgent needs of many geophysical organizations and worthy projects in contemplation.

(4) *Bibliography of microfilms and publications*—It is recommended that a complete bibliography of microfilms and publications be prepared. The Sub-Commission has prepared, as far as possible in the limited time available, partial lists which will serve as a starting point for final compilation; the Danish Meteorological Institute no doubt has further material in this regard.

(5) *Historical summary of Polar Year 1932-1933*—Anyone who has had occasion to seek material and results concerning the First International Polar Year of 1882-1883, has experienced the disappointment of finding nowhere a summary of the activities and publications of that enterprise

*A final grant of $12,000 was made by the Rockefeller Foundation by its Board of Trustees, December 2-3, 1947.—*Ed.*

although there are numerous valuable contributions which came directly from its results. The Sub-Commission regards as of first importance the preparation, publication, and wide distribution of a comprehensive, authoritative historical summary of the Polar Year 1932-1933 and of suitable condensations thereof for publication in several leading scientific journals, for example, *Nature* and *Science*. It seems important that this summary should include lists of (*a*) official resolutions relating to the enterprise by reference to published sources and by publication of those not so far published, (*b*) complete lists of organizations and nations taking part and of their contributions, (*c*) complete lists of stations, personnel, equipment, and programs followed.

(6) *Suggested classification for liquidation of agenda*—It is recommended that the liquidation of the agenda be accomplished through the allocation of the items into four sections: (*a*) Meteorology and allied results; (*b*) Geomagnetism, earth-currents, atmospheric electricity, and allied results; (*c*) Auroral results; and (*d*) Aerological results. Information on various projects and fields of investigation, some heretofore arranged, some partly completed, and others suggested will form a basis for consideration by the Sub-Commission for assignment to the several sections. Certain of the older suggestions are subject to modification by reason of the work done since 1939, particularly in meteorology and aerology. One meteorological subject of unique importance is a study of the climatological character of the Polar Year. It appears that there is still much research to be done in the analyses of the geomagnetic data, including publication of magnetic vector-diagrams already in manuscript, studies of geomagnetic activity, and discussions. The extensive auroral results still await general analysis and discussion.

Conclusion

The accomplishment of the program of the Second International Polar Year of 1932-1933 was heroic. It would be a calamity and an injustice to those who gave so generously in effort and time not to see its work completed in respect to thorough compilation, analysis, discussion, and publication as a whole enterprise. The Sub-Commission hopes that the International Meteorological Organization may give official and formal approval to the several recommendations submitted. Prompt action is needed if we are to realize the terminal date set as December 31, 1950.

[Note: The report was accompanied by enclosures (62 pages) under the following subjects: On funds and Central Bureau; on status progress as of 1946; on recommendations for liquidation of agenda; on bibliography; and on progress of Polar-Year 1932-1933 activities as reported, by the Secretary of the International Commission for the Polar Year 1932-1933, to the Extraordinary Conference of Directors at London during February 25 to March 2, 1946.]

Washington, D. C., U. S. A., September 30, 1947

NOTES

(See also pages 468, 477, 492, and 496)

(58) *Personalia—James H. Baden* and *Ernest N. Weber*, Geophysicists of the United States Coast and Geodetic Survey, are making magnetic observations in the western part of the United States.

William E. Wiles, Geophysicist of the United States Coast and Geodetic Survey, left October 15, 1947, to make magnetic observations in New England.

Three junior officers of the Philippine Bureau of Coast Surveys spent one month in the Division of Geomagnetism and Seismology and at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey, for instruction in magnetic observations and processing records.

R. E. Gebhardt is now in charge of the Cheltenham Magnetic Observatory. *Ronald L. Viets*, Geophysicist, reported for duty at the Cheltenham Magnetic Observatory on October 6, 1947.

Four observers from the United States Hydrographic Office were given instruction at the Cheltenham Magnetic Observatory in the use of the Kew magnetometer and the dip-circle.

J. B. Fenner, Geophysicist of the United States Coast and Geodetic Survey at the Cheltenham Magnetic Observatory, has recently resigned.

Dr. *V. C. A. Ferraro*, frequent contributor to the JOURNAL, was recently appointed Professor of Applied Mathematics at Exeter University College.

Dr. *F. J. M. Stratton*, General Secretary of the International Council of Scientific Unions, held conferences in Washington, while en route to the Assembly of UNESCO in Mexico City, with Dr. *J. A. Fleming*, President of ICSU, and members of the National Research Council, November 2-5, 1947.

Dr. *Santilal Banerjee*, of the Physical Laboratories, Council of Scientific and Industrial Research, Delhi, India, is a visiting investigator in geophysics at the Department of Terrestrial Magnetism, Carnegie Institution of Washington. His interests are chiefly in theoretical seismology, terrestrial magnetism, and atmospheric electricity. Before proceeding to Washington, Dr. Banerjee studied for some time at Columbia University.

Grote Reber, Radio Physicist and Engineer, who has recently joined the staff of the Radio Propagation Laboratory of the National Bureau of Standards, will direct several new projects centered on the study of cosmic and solar radio noise. He is supervising erection of a German Giant Wurzburg, a large and powerful radar device, that will be used to detect solar and cosmic radiations that penetrate the Earth's atmosphere.

Dr. *Otto Burkard* is now provisional Director of the Institute of Meteorology and Geophysics at the University of Graz (Halbärthgasse 1, Graz, Austria). Dr. Burkard succeeded Dr. *Kurt Wegener*, who was retired in 1946 and who is now engaged in scientific research in South America.

Dr. *R. Meldrum Stewart* retired from the position of Dominion Astronomer of Canada last February. He is succeeded by Dr. *C. S. Beals*.

INTERNATIONAL ASSOCIATION OF TERRESTRIAL MAGNETISM AND ELECTRICITY*

By J. W. Joyce

Circular Letter No. 1, concerning plans for the Eighth General Assembly of the International Union of Geodesy and Geophysics to be held at Oslo, Norway, 17-28 August 1948.

(I) *The time and place*—After long postponement caused by the exigencies of War, the Eighth General Assembly of the International Union of Geodesy and Geophysics will be held during August, 1948, in Oslo, Norway. The Norwegian Committee in Charge of Arrangements has set tentative dates of August 17-28, 1948, for the meetings. The first two days will be devoted to administrative and organizational matters.

(II) *Special significance*—The importance of the Eighth General Assembly as an initial step in the return to normal peacetime activity of the Union, and as a meeting in which stock can be taken, after a lapse of nine years, of the accumulation of scientific and technical subjects for discussion can hardly be overestimated. Reports of National Committees covering activities of various countries in the fields of Terrestrial Magnetism and Electricity for the period 1939-48 should not only aid in evaluating the present status of these studies in each country, but should also indicate the best means for continuing current projects and stimulating new ones of international scope. Most of the technological advances made during the war years are now available for application to scientific problems, many of which are of particular interest to the Union. The function of the Union in facilitating international support for these applications is manifest.

(III) *Proposed agenda*—The following proposed agenda are submitted for comment and suggestion:

(1) Proposals of National Committees
(2) Reports of National Committees
(3) Reports of the following Committees and Individual Reporters appointed at the Washington Assembly:
- (*a*) Committee on the Selection of Sites of New Observatories for Terrestrial Magnetism and Electricity (Jno. A. Fleming, Chairman)
- (*b*) Auroral Committee (C. Störmer, Chairman)
- (*c*) Committee on the Study of the Relationship between Solar Activity and Terrestrial Magnetism (Jno. A. Fleming, Chairman)

*It is urged that all interested geophysicists and geophysical organizations communicate suggestions and comments promptly, in relation to the Oslo Assembly, to the Secretary and Director of the Central Bureau of the Association.—*Ed.*

(*d*) Committee on Magnetic Secular-Variation Stations (N. H. Heck, Chairman)
(*e*) Committee on Ionic Equilibrium (O. H. Gish, Chairman)
(*f*) Committees on Magnetic Charts
  (1) Organization of the Work (H. Spencer-Jones, Chairman)
  (2) Methodology (Acting Chairman to be selected)
(*g*) Committee on Registration in Iceland of Giant Pulsations (Acting Chairman to be selected)
(*h*) Committee on Classification of Magnetic Literature (H. D. Harradon, Chairman)
(*i*) Committee on Methods of Observatory Publications (Ch. Maurain, Chairman)
(*j*) Committee to Promote International Comparisons of Magnetic Standards (Acting Chairman to be selected)
(*k*) Committee on Observational Technique (H. E. McComb, Chairman)
(*l*) Committee on Three-Hour-Range Indices for Magnetic Characterization (J. Bartels, Chairman)
(*m*) Joint Committee of the Commission of Terrestrial Magnetism and Atmospheric Electricity and of the Association on Methods and Codes to Adequately Describe Magnetic Disturbances and Perturbations, including a report on the Polar Year 1932-33 (Jno. A. Fleming, Chairman)
(*n*) Joint Committee of the Association and of the International Scientific Radio Union (E. V. Appleton, Chairman)
(*o*) Reporter on International Collaboration for Promoting the Study of the Influence of the Moon on Geophysical Phenomena (Sydney Chapman)

(4) Remarks to be submitted to existing Committees and Reporters
(5) Miscellaneous communications on subjects concerning terrestrial magnetism and electricity (in the form of technical papers)
(6) Subjects for general discussion
(7) Subjects for deliberation by committees, including proposals for the appointment of new committees and reporters
(8) Resolutions

In addition to the above items, the Agenda will include the Address of the President, the reports of the Secretary and Director of the Central Bureau, a report on magnetic characterization of days, and the election of officers of the Association.

Communications dealing with international aspects of terrestrial magnetism will be specially welcome. Such subjects may, for example, include consideration of the development and use of airborne magnetic surveying

instruments, the continually pressing need for additional land and sea observations taken at the Earth's surface, improvement in instrument designs and techniques, and many similar problems.

(IV) *Urgency of submitting promptly, comments, papers, reports*—Considering the estimated backlog of reports and articles, the Secretary suggests that scheduling of a Provisional Program will be a task of some magnitude. It is urgently requested, therefore, that all organizations and individuals interested in the coming meeting submit titles of reports, technical and scientific communications, proposed resolutions and comments to the Secretary of the Association, Dr. J. W. Joyce, 6641-32nd Street, N. W., Washington 15, D. C., U. S. A., by October 30, 1947. On the basis of the material received, a more complete provisional program will be outlined and forwarded during November. The final Agenda must, in accordance with the Statutes of the Association, be distributed four months in advance of the Assembly. This will establish a deadline date of March 15, 1948 for agenda items to be included in the Ordre du Jour.

(V) *Distribution of this letter*—Every effort has been made to give this letter the widest possible circulation on the basis of mailing lists now available to the Secretary. To avoid any inadvertent omissions it will be appreciated if recipients will promulgate the contents of this letter to all organizations and individuals known by them to be interested in terrestrial magnetism and electricity.

(VI) *New secretaryship*—The Executive Committee has, with regret, acceded to the request of Dr. A. H. R. Goldie that he be relieved of the responsibilities of the office he has so ably filled since his election in 1936. Until the election of officers at the Oslo meeting, the Committee has appointed as Interim Secretary Dr. J. W. Joyce, whose mailing address is 6641-32nd Street, Northwest, Washington 15, D. C., U. S. A. and whose telegraphic address is TERMAGEL, Washington.

Washington 15, D. C., U. S. A., September 10, 1947

Special Circular Letter A, to International Committee Chairmen, and other representatives and observatories, concerning *control of variometer magnets.*

The Washington Assembly of 1939 passed two Resolutions concerning the control of variometer magnets. These Resolutions read as follows.

(4) Control of variometers and absolute instruments

(*a*) The Association reaffirms its Resolution 3 adopted at the Edinburgh Assembly of the great need of examination at regular intervals, at least every two years, of magnetic instruments, including the control of the direction of the magnetic axes of the magnets in variometers.

(*b*) The Association recommends that instruments used for the determination of declination and inclination are adjusted so that their corrections do not exceed the standard error of a single observation.

(10) Recommendations regarding publication of observatory data

(*e*) Information and data regarding reliability of values and proper performance of variometers and magnetometers such as orientation of magnets, absolute observations and base-line determinations, scale-value determinations, temperature-coefficients, comparisons of absolute instruments with others and with standard instruments, etc.

Danish and Swedish geomagneticians represented by Dr. Johannes Olsen, Dr. V. Laursen, Dr. J. Egedal, Dr. Nils Ambolt, and Dr. Sven Åslund, have proposed that the various observatories submit to their respective national groups, for inclusion in the national reports to be submitted at the Oslo Assembly, information concerning steps taken to adhere to the above Resolutions. It is therefore requested that this action be taken.

Washington 15, D. C., U. S. A., October 24, 1947

Circular Letter No. 2, concerning plans for the Eighth General Assembly of the International Union of Geodesy and Geophysics to be held at Oslo, Norway, 17-28 August 1948.

(I) *Proposed agenda*—Two significant additions have been made to the tentative agenda of the Association as reported in Circular Letter No. 1 of September 10, 1947. First, it has been proposed that a joint meeting be held with the International Association of Meteorology: the subject for discussion will be "Physics of the Upper Atmosphere and the Ionosphere." Second, it has been proposed that one of the sessions of the Association be devoted to the subject of "Air and Ocean World Magnetic Surveys." Additional technical communications on the above subjects are urgently solicited.

The selection of Acting Chairmen to replace original appointees no longer available because of death, illness, or special circumstances, has been completed. The Committees so effected are as follows:

Committee on Magnetic Secular Variation Stations, E. H. Vestine

Committee on Magnetic Charts—Methodology, E. H. Vestine

Committee on Registration in Iceland of Giant Pulsations, Johannes Olsen

Committee to Promote International Comparisons to Magnetic Standards, J. Keränen

Committee on Three-Hour-Range Indices for Magnetic Characterization, A. G. McNish

(II) *National Reports*—The importance of receiving National Reports through the various National Committees is again stressed. Countries not now adhering to the Union are also cordially invited to submit National Reports. These reports, intended to describe the activity in various countries since 1939, will constitute one of the most valuable features of the coming Assembly and the published *Transactions*. Abstracts of these reports should be prepared for presentation at the meeting. The Central Bureau will reproduce copies of such reports received before April 30, 1948, and will distribute them at Oslo.

(III) *Communications*—While the response to the initial request for communications on technical subjects of international scope has been good, additional papers are still desired. Titles, and up to 100 copies of the documents, should be forwarded to the undersigned Secretary of the Association as soon as possible, since the deadline date for such material remains March 15, 1948. Where facilities are not available for making the required number of copies for distribution at Oslo, the Central Bureau will, as far as possible, undertake to make the necessary copies provided the manuscripts are received not later than March 15, 1948.

(IV) *Proposals for the agenda*—National Committees are reminded that it is their right to submit subjects for discussion. All such proposals will be most welcome. This also applies to instructions or comments for Committees, proposed resolutions, and similar material.

(V) *Confirmation of addresses*—The Secretary is undertaking the preparation of a comprehensive and world-wide mailing list of individuals and organizations interested in Terrestrial Magnetism and Electricity. He will, therefore, welcome confirmation of, or correction to, addresses used in the mailing of this Circular Letter, as well as addresses of interested colleagues in each country.

(VI) *Increasing interest*—The Secretary is gratified to report the many replies already received in answer to Circular Letter No. 1. These responses show an increasingly active world-wide interest in Terrestrial Magnetism and Electricity. A most interesting and challenging Assembly is predicted.

Washington 15, D. C., U. S. A., December 24, 1947

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

July to September, 1947

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or 9^h 01.^{m}3 W. of Gr.)

July 17-23—Climaxing a short period of very quiet magnetic conditions a fairly severe storm began abruptly at 17^h 50^m GMT, July 17. During the first fourteen hours activity was limited to short-period, low-amplitude oscillations; however, at about 08^h, July 18, this activity was replaced by rather deep bays of short duration. Between 10^h and 13^h a very deep bay occurred in H, which gave a K-index of 8; however, the most violent activity of the storm took place during the fourteenth hour of July 18 when there was recorded short-period, large-amplitude oscillations producing a K-index of 8. The intensity of the storm began to diminish at about 18^h, July 18, but moderately disturbed conditions continued until about 18^h, July 20. During the following three days only slight disturbances occurred but at about 06^h, July 23, activity began to increase. For the period 09^h-12^h, July 23, a K-index of 7 was recorded. The storm may be said to have ended at 12^h, July 23, but lesser disturbances were recorded for several days following.

August 11-12—A minor storm began rather abruptly at 02^h 50^m GMT, August 11, but activity was only slight until about 12^h of the same date. After midday on August 11, Z began to slowly decrease and during the following three hours the decrease amounted to about 110γ. During the fifteenth hour Z began to increase and continued to do so until 24^h, August 11. At about 00^h 20^m, August 12, all elements began to show signs of renewed disturbance and between 03^h and 10^h of this date the most disturbed portion of the storm occurred, producing K-indices of 6, 7, and 7. The storm may be said to have ended at about 12^h, August 12; however, there were short-period, low-amplitude oscillations in all elements for several days following.

August 15-27—A moderate storm of rather long duration began abruptly at 09^h 52^m GMT, August 15, with the forming of rather large bays in all elements. During the first three hours of the storm H decreased and recovered about 700γ while Z likewise decreased and recovered some 340γ. Activity subsided somewhat at about 13^h and continued only slightly disturbed by short-period, low-amplitude oscillations until about 23^h, August 15. However, between 23^h, August 15, and 03^h, August 16, there again appeared large bays in H and Z and for seven hours following these bays there was almost no disturbance. At 09^h 54^m, August 16, there was a sharp increase in storminess and during the next seven hours violent activity occurred. At 17^h, August 16, the storm again subsided but 06^h, August 17,

found renewed activity and all elements once more became very disturbed. This condition continued until about 16^h, August 17, at which time there was another lull. Rather disturbed conditions again appeared at about 08^h, August 18, when large bays began to form but at $16^h\ 30^m$, August 18, this condition disappeared and again there was a lull period made up of short-period, low-amplitude oscillations. Activity began to increase at 08^h, August 19, and became rather violent at 09^h. This violent activity continued until 17^h of the same date and from then until about 08^h, August 22, there was only slight disturbance with no violent activity. However, between 08^h and 12^h, August 22, the most violent disturbance of the storm took place. This activity consisted of short-period, large-amplitude oscillations and produced a K-index of 9. After 12^h, August 22, the character of the storm changed to short-period, low-amplitude oscillations which continued until $07^h\ 30^m$, August 23, when there was another change in the character of activity. This change brought rather small, irregular bays which continued until the storm finally died out at about 14^h, August 27.

September 2-4—A moderate disturbance began sharply at $23^h\ 27^m$ GMT, September 2. During the first eight and one-half hours activity was slight and in the form of short-period, low-amplitude oscillations. However, at 08^h, September 3, there was a marked increase in storminess when the activity suddenly changed to short-period, large-amplitude oscillations, producing a K-index of 9. At 11^h, September 3, the intense activity was replaced by short-period, low-amplitude oscillations superposed on irregular bays. This condition continued until about 19^h, September 4, when the storm may be said to have ended. However, moderate disturbances were recorded for several days following.

September 13-18—A moderate storm of long duration began gradually at about 00^h GMT, September 13. At about $08^h\ 30^m$, September 13, there was a sharp increase in activity which continued until about 14^h of the same date. This activity consisted of moderately long-period oscillations of large amplitude and produced a maximum K-index of 8. The disturbance subsided after 14^h and all elements were practically undisturbed until about 04^h, September 14, when there was another sharp increase in storminess. This increased activity continued until 19^h, September 14, and produced K-indices of 7, 7, and 8. During the following 32 hours or until 03^h, September 16, there was continued disturbance of moderate intensity but with no violent activity. Between 03^h, September 16, and 02^h, September 17, there was a lull, however after 02^h there was renewed activity which continued until about 15^h, September 18. The storm may be said to have had its ending at about 15^h, September 18, but there were several flare-ups, especially during the local dark hours during the following several days.

September 22-26—A moderate storm which is undoubtedly a continuation of the disturbance described above began gradually at about 04^h GMT,

September 22. After a two-hour period of intense activity, which occurred between 10^h and 12^h, September 23, and produced a K-index of 8, there was a lull period of no disturbance. At about 09^h, September 24, there was renewed activity which consisted of short-period, large-amplitude oscillations and during the following twenty-eight hours or until 13^h, September 25, the most violent activity of the storm occurred. K-indices for this period were 7, 8, 8, 6, 6, 7, 8, 9, 8, and 7. The storm finally died out at about 03^h, September 26.

September 30—A moderate disturbance began suddenly at $18^h\ 08^m$ GMT, September 30; there was, however, no intense activity before the end of the quarter.

Joel B. Campbell, *Observer-in-Charge*

Witteveen Magnetic Observatory

April to September, 1947

(Latitude 52° 48′.8 N., longitude 6° 40′.1 or $0^h\ 26^m.7$ E. of Gr.)

April 2—A small disturbance (probably a solar-flare effect) was recorded from $10^h\ 15^m$ to about $10^h\ 28^m$ GMT.

April 3-5—A period of minor disturbance began suddenly at $15^h\ 01^m$, GMT, April 3, and lasted thirty-six hours.

April 6—A very intense solar-flare effect (accompanied by radio fade-out) was recorded from $11^h\ 52^m$ to about $12^h\ 14^m$ GMT. Deviations: D, $-6'.2$ westerly; H, -65γ; Z, -4γ.

April 8-9—A minor disturbance started with a strong sudden commencement (100γ in H) at $21^h\ 50^m$ GMT, April 8, and lasted to about 16^h, April 9. One K-index of 5 occurred in the last three-hour period on April 8.

April 17-20—After a series of radio fade-outs between 09^h and 20^h GMT, April 15, there was a sudden commencement of a magnetic disturbance at $12^h\ 25^m$, April 17. The disturbance that followed gradually increased (K-indices of 5 and 6 in the fifth and sixth three-hour intervals) and reached its main phase between 20^h and 23^h, April 17. In this interval storm-activity occurred and an intense display of Aurora Borealis took place: two K-indices of 8 were noted and at about 22^h the corona was formed while auroral forms were seen up to about 50° above the south horizon. From 00^h, April 18, to 20^h, April 20, activity was light in general. A typical bay between 21^h and $22^h\ 20^m$, April 18, gave rise to a K-index of 6 and an auroral glow occurred.

May 6—A typical solar-flare effect (accompanied by radio fade-out) was recorded from $10^h\ 15^m$ GMT to about $10^h\ 26^m$. Deviations: D, $+1'$ westerly; H, $-\ 20\gamma$; Z, $-\ 3\gamma$.

May 13-18—A minor disturbance started gradually at about 17^h GMT, May 13, and ended at about 24^h, May 18. A period lasting forty-eight hours of generally moderate activity followed on an abrupt commencement

at 00^h 17^m, May 15; only one K-index of 5 was noted in this period. A typical solar-flare effect (accompanied by a complete radio fade-out) was recorded from 12^h 45^m to about 13^h 00^m, May 16. Two K-indices of 5 occurred in the interval from 15^h-21^h, May 18.

May 19—A weak solar-flare effect (accompanied by radio fade-out) was recorded from about 11^h 42^m to about 12^h 05^m GMT.

May 21-24—Strong Dellinger effects in the radio traffic with North and South America occurred from 18^h 25^m to about 19^h 12^m GMT, May 21, and from 18^h 52^m to about 19^h 17^m, May 22. Magnetic deviations during these intervals amounted to $+12\gamma$ in H and $-2'$ westerly in D, respectively, no deviation in H and $-1'.5$ westerly in D. At 22^h 42^m, May 22, a strong sudden commencement was recorded. Magnetic activity temporarily revived after an abrupt commencement at 02^h 39^m, May 23, but was only slight after 06^h 20^m, May 23. After a sudden commencement at 06^h 44^m, May 24, the disturbance was moderate till about 09^h 20^m and then gradually declined.

May 29—The occurrence of a strong positive bay (mainly in H, with maximum at 15^h 26^m) from about 14^h 30^m GMT to about 16^h 00^m (with K-indices of 5 and 6 for the fifth and sixth three-hour intervals) was coupled with strong effect on radio traffic, mainly from 14^h 30^m to 15^h 10^m.

May 30—A weak but typical solar-flare effect was recorded from 14^h 15^m to about 14^h 23^m GMT. It was accompanied by radio fade-out. Deviations: D, $+1'$ westerly; H, -6γ; Z, -1γ.

May 31-June 1—Magnetic activity gradually increased from 08^h GMT, May 31, reached a maximum between 23^h, May 31, and 05^h, June 1, and decreased quickly. One K-index of 5 was recorded. After about 14^h, June 1, conditions were practically normal.

June 2—A weak solar-flare effect was recorded from 14^h 12^m to 14^h 20^m GMT.

June 5-6—After a sudden commencement at 07^h 26^m GMT, June 5, there was occasionally moderate disturbance till about 02^h, June 6; three K-indices of 5 were noted. During lightly disturbed conditions a solar-flare effect (accompanied by a complete radio fade-out) was recorded from 10^h 43^m to 11^h 20^m; deviations: D, $+4'$ westerly; H, -40γ; Z, -7γ.

June 13-14—A sudden commencement occurred at 17^h 48^m GMT, June 13. Magnetic activity was insignificant from 18^h 30^m to about 22^h. From about 22^h 45^m, June 13, the disturbance was occasionally strong; at about 22^h, June 14, the disturbance had almost ended. During generally lightly disturbed conditions a typcial solar-flare effect (accompanied by a complete radio fade-out) was recorded from 10^h 36^m to about 11^h 30^m; deviations: D, $+9'$ westerly; H, -30γ; Z, -30γ. Other sudden commencements of renewed strong activity occurred at 17^h 26^m and 19^h 31^m, June 14, mainly in H.

June 17—A disturbance abruptly commenced at 03^h 01^m GMT and

lasted throughout the day. From 03^h to 07^h the field was unquiet. From 14^h to about 21^h the disturbance increased and one K-index of 5 was recorded.

June 19—A weak solar-flare effect was recorded between $10^h\ 52^m$ and $11^h\ 06^m$ GMT.

July 17-19—About $10^h\ 38^m$ GMT, July 17, a first indication of increasing magnetic activity. At $17^h\ 48^m$, July 17, a moderate magnetic storm suddenly commenced. With K-indices of 7, 8, and 6 (owing to variations in H only) for the last nine hours of July 17, magnetic activity was exhausted for the greater part. On July 18, the K-sum was 37, three K-indices of 5 and one of 6 were noted. The storm ended about 12^h, July 19. An intensive display of Aurora Borealis was observed from 22^h, July 17, to $01^h\ 25^m$, July 18. Ranges: D, 45′; H, 630 γ; Z, 110 γ.

August 1—A typical solar-flare effect was recorded from $15^h\ 17^m$ to $15^h\ 21^m$ GMT, mainly in D (increase of 7′.5); it was accompanied by a complete radio fade-out.

August 7—A weak solar-flare effect was recorded from $12^h\ 46^m$ to about $13^h\ 00^m$ GMT, mainly in D (increase of 1′.5); the radio traffic in all directions was only moderately affected, no interruption occurred.

August 11-25—A period of generally moderately disturbed conditions.

August 12—Before noon a moderate polar disturbance occurred, which began abruptly at $00^h\ 20^m$ GMT. About $14^h\ 07^m$ a radio fade-out was observed.

August 13—Magnetic activity gradually increased reaching a K-index of 5 between 15^h and 18^h GMT.

August 15-16—At $09^h\ 51^m$ GMT, August 15, a gradually increasing disturbance started suddenly. It reached its maximum between 00^h and 01^h, August 16, when a K-index of 7 was noted; after 02^h, August 16, the deviations were small with exception of the Z-variation in the afternoon; Aurora Borealis was observed in the last hours of the evening and in the first hours of that night. Four K-indices of 5 and one of 6 occurred in the last fifteen hours of August 15. Ranges: D, 64′; H, 460 γ; Z, 260 γ.

August 17—Between 15^h and 24^h GMT, magnetic activity increased temporarily and two K-indices of 5 and one of 6 were noted.

August 18-21—Days with a mean K-index of nearly 4. Activity was mostly highest in the hours round 18^h GMT and one K-index of 5 occurred on each day. About $01^h\ 30^m$, August 20, weak auroral forms were seen.

August 22-23—At $09^h\ 12^m$ GMT, August 22, a strong polar storm started suddenly. Activity was highest in the first three hours and gave rise to a K-index of 8. From 12^h to 23^h the disturbance gradually decreased, but soon after midnight activity increased again temporarily and reached a K-index of 6. Between 13^h and 19^h, August 23, two indices of 5 occurred. Ranges: D, 51′; H, 530 γ; Z, 140 γ.

August 24-25—Magnetic activity gradually decreased. From $13^h\ 44^m$ to

14^h 00^m GMT, August 24, a small disturbance (probably a solar-flare effect) was recorded. It was accompanied by a radio fade-out in the traffic with United States of America (information was incomplete owing to reduced service on Sunday).

August 31—During weakly disturbed conditions a solar-flare effect (accompanied by a complete radio fade-out) was recorded from 14^h 55^m to about 15^h 16^m GMT. Deviations: D, $3'.5$ westerly; H, 15 γ.

September 2-4—After two indications of increasing magnetic activity, at 12^h 53^m and 14^h 18^m GMT, September 2, and a typical Dellinger effect in the radio traffic with South and North America from 18^h 05^m to about 18^h 35^m, there was a sudden commencement at 23^h 28^m, September 2. The disturbance was slight till about 06^h 22^m, September 3, when it entered suddenly into the storm-phase. Storm-activity occurred until 10^h 20^m, moderate activity had subsided by 24^h, September 3. Activity temporarily revived between 13^h 45^m and 19^h 40^m, September 4, when at various moments (13^h 45^m, 14^h 44^m, 15^h 34^m, and 16^h 18^m) strong variations occurred that resembled sudden commencements. Ranges: D, $51'$; H, 285 γ; Z, 140 γ. It seems noteworthy that on September 3, radio traffic was not affected until 18^h 45^m. Aurora was seen about 20^h 15^m, September 3.

September 5-6—At 18^h 02^m GMT, September 5, a weak disturbance commenced; at 03^h, September 6, it had nearly ended.

September 7-8—At 14^h 18^m GMT, September 7, a moderate disturbance started abruptly. At 16^h 12^m, September 7, activity suddenly revived so that for the last nine hours of September 7 three K-indices of 5 were noted. Aurora Borealis was seen about 20^h 30^m, September 7; the observation ended soon as a result of the rising moon.

September 11-15—This period of magnetic activity with only temporarily moderate disturbances started abruptly at 15^h 44^m GMT, September 11, with a bay-disturbance mainly in H. Magnetic activity gradually increased and in the last three-hour interval on September 13, a K-index of 6 was noted for a bay-disturbance. On September 14, there was no K-index beneath 4; between 15^h and 21^h, K-indices of 6 and 5 were noted. At 14^h 55^m, September 15, there was a suddenly commencing disturbance that had nearly ended at 22^h, September 15; three K-indices of 5 occurred between 15^h and 24^h. Aurora was seen: From 21^h 25^m, September 12 until 00^h 50^m, September 13; from 21^h 40^m to 22^h 05^m, September 13; from 21^h 05^m to about 21^h 40^m, September 14; and from 20^h 00^m to 21^h 20^m, September 15; the intensity was weak in general.

September 16-18—After 16^h GMT, September 16, there was gradually increasing activity. September 17 and 18 had a mean K-index of 4, with three K-indices of 5 occurring before 04^h and after 17^h, generally during bays. Aurora was seen from about 21^h, September 17, to about 03^h, September 18.

September 22-23—Twenty-four hours of moderate activity began about 15^h GMT, September 22. After some bays in the period ending 01^h, September 23, there was an abrupt commencement at 03^h 26^m followed by a moderate disturbance that ended about 14^h, September 23. Three K-indices of 5 were noted.

September 24-25—From 00^h GMT, September 24, a gradually increasing disturbance which after 14^h, September 24, quickly developed to a moderate magnetic storm. In the afternoon, September 24, the most important feature was a deviation in Z of 240 γ above normal. The greatest activity took place between 18^h and $20\frac{1}{2}^h$, September 24, and from 23^h, September 24, until about 06^h, September 25. The disturbance had nearly subsided by 24^h, September 25. In spite of moonlight until about 23^h, a fine display of Aurora Borealis was seen from 18^h 50^m, September 24, to 03^h 20^m, September 25. In the interval between 12^h, September 24, and 09^h, September 25, three K-indices of 7, two of 6, and two of 5 were noted. Ranges: D, 80′; H, 390 γ; Z, 380 γ.

September 30—At 18^h 09^m GMT, September 30, there was a sudden commencement of a magnetic disturbance which was only weak in the beginning.

Addendum for March 15, 1947—A gradually increasing disturbance started suddenly at 08^h 43^m GMT. It reached its maximum at about 16^h with a bay-like feature especially in H and Z, giving rise to a K-index of 6 for the sixth and one of 5 for the fifth three-hour-interval. After 18^h the disturbance was only slight.

H. P. Th. van Lohuizen, *Leader of the Observatory*

Cheltenham Magnetic Observatory
July to September, 1947

(*Latitude 38° 44′.0 N., longitude 76° 50′.5, or 5^h $07^m.4$ W. of Gr.*)

July 17-20—A moderately severe magnetic storm began with a sudden commencement in all three elements at 17^h 49^m GMT, July 17, the severest part of the storm occurring within the first eight hours. Initial H-motion was rapid and of large amplitude. After soon reaching a low value of 18,177γ at 18^h 06^m, H then increased 265 γ in a rapid although erratic manner until 20^h 22^m. After about 03^h, July 18, H exhibited rapid pulsations of moderate amplitude. After 03^h, July 19, long-period motion of comparatively small amplitude predominated until the end of the storm at 17^h July 20. Minimum H of 18,074 γ occurred at 14^h 36^m, July 18. Following the sudden commencement Z decreased until 18^h 01^m, after which a rapid steady increase set in until 00^h 08^m, July 18, a change of 288 γ being recorded. Z then decreased until 04^h, when normal values were resumed. Z showed a rather rapid rise between 16^h and 20^h, July 18, and was erratic between 01^h and 07^h, July 19.

At the outset of the storm, D was irregular, the oscillations being of large amplitude. West declination increased 43′ between 20^h 08^m and 21^h 06^m, July 17, at which time a westerly extreme was recorded. Rapid oscillations superimposed on long-period motion prevailed between 05^h and 18^h, July 18. A second rapid increase in west declination occurred between 02^h 29^m and 03^h 02^m, July 19, 30′ change being scaled. Three successive K-indices of 7 were recorded for the three intervals from 18^h, July 17, to 03^h, July 18. The K-sum for July 18 was 38.

August 12—A comparatively minor, short-lived disturbance showing irregular oscillations in all three elements occurred between 00^h and 11^h GMT, August 12. Two K-indices of 5 were recorded for the second and third intervals of the day. Ranges: D, 30′; H, 119 γ; Z, 64 γ.

August 15-25—An unusually prolonged magnetic storm, which was severe in parts and otherwise generally disturbed throughout, began with a sudden commencement in all three elements at 09^h 51^m GMT, August 15. The K-figures indicate the extent of the disturbance; there were nine consecutive Greenwich days, beginning with August 15, where the daily K-sums were 32 or higher. The highest K-sum of 41 occurred on August 22, a 9 being recorded for the fourth interval of that day. At the time of the sudden commencement, H suddenly increased 63 γ and rapid oscillations took place in all elements. Near 17^h, August 15, both H and Z began to increase gradually, the increase becoming rapid at about 21^h. H reached a high value at 22^h 01^m and then decreased very rapidly until 00^h 55^m, August 16, a range of 327 γ being scaled for this period. Z reached a maximum value for the entire storm-period at 23^h 56^m, August 15, having increased 339 γ from 16^h 21^m until that time. During this disturbed period D reached a high westerly value at 22^h 59^m, August 15, and then rapidly decreased 43′ until 00^h 02^m, August 16. After the severe disturbance just described, all elements remained disturbed for more than six days. The disturbance consisted mostly of irregular motion and was rather uniform throughout, wide fluctuations, especially in D but also in Z, occurred a number of times. At 09^h 11^m, August 22, a storm within a storm began with a sudden commencement of violent activity in all three elements. For three hours all three elements were greatly disturbed, very rapid motion of large amplitude taking place. Both Z and H decreased rapidly, Z falling 655 γ between 09^h 11^m and 10^h 36^m, at which time minimum Z for the storm occurred. H decreased 986 γ between 09^h 11^m and 10^h 33^m, minimum H of 17,337 γ taking place at that time. During this period D also was greatly disturbed. At the sudden commencement at 09^h 11^m, west declination suddenly decreased 11′. West declination then increased rapidly by 115′ until 10^h 31^m, when a westerly extreme for the storm was recorded. Following the intense disturbance, rapid oscillations occurred in all elements between 12^h, August 22, and 01^h, August 23. During the first hour of August

23, a sharp peak in H occurred, the element suddenly increasing 113 γ in two minutes at 00^h 06^m and then rapidly reassuming its previous position. Between 01^h and 08^h, August 23, pronounced irregular motion was recorded for all elements. For this period D exhibited a range of 32′ and Z of 120 γ. For the next two and half days the disturbance was comparatively minor but a number of wide irregular variations in D occurred thus extending the rather arbitrary ending of the storm at 12^h, August 25.

September 2-4—A moderate magnetic storm began at 23^h 26^m, GMT, September 2, with a sudden commencement in all three elements. The activity was minor until 06^h, September 3, when the disturbance in H increased. The disturbance was greatest in all elements between 08^h and 11^h, September 3, when both H and Z exhibited depressions. H increased until 08^h 08^m and then decreased 237 γ until 10^h 07^m. Z decreased 208 γ between 08^h 00^m and 08^h 56^m. D was irregular during this period, west declination decreasing 34′ between 08^h 29^m and 09^h 18^m. Between 11^h and 24^h, rapid oscillations of moderate amplitude in H predominated. The perturbations changed to long-period and irregular motion until 14^h, September 4, when five more hours of rapid oscillations in H occurred. A well-defined bay occurred in D centered around 06^h, September 4, at which time a depression occurred in Z. The storm ended at about 20^h, September 4. The K-sum for September 3 was 39 with a 7 and 6 occurring in the third and fourth three-hour intervals of that day.

September 12-26—This was a prolonged period of disturbance with the exception of a few rather quiet intervals. The disturbance began at 21^h GMT, September 12. Irregular oscillations of moderate amplitude in all elements predominated until 23^h, September 15. A sharp depression occurred in D between 02^h and 03^h, September 13. The K-sums for September 13, 14, 15 were 36, 36, 34, respectively. From 23^h, September 15, to about 19^h, September 16, the record was generally quiet but the disturbance began again at 19^h in H, Z, and D becoming disturbed later at 23^h. Again generally irregular oscillations of moderate amplitude prevailed for a number of days.

There were no very outstanding characteristics during this period although a K-index of 6 arising from D was scaled for the first interval of September 18. A well-defined depression in D occurred on September 18, centered around 23^h 05^m. Between about 12^h, September 19, and 04^h, September 22, the record was rather quiet but just near 04^h the disturbance broke out again in all elements. D was rather badly disturbed for a few hours. Irregular oscillations of moderate amplitude predominated up to 14^h, September 23. A quiet period again followed until 03^h, September 24, when all elements again became disturbed. At 12^h, September 24, the storm suddenly became severe. H decreased 242 γ between 12^h 21^m and 15^h 44^m. Z increased rapidly changing 284 γ between 14^h 00^m and 19^h 17^m. D was irregular in this

interval. Between 19^h, September 24, and 08^h, September 25, the storm was severe in all elements, the disturbance being irregular. Z decreased 406 γ and H decreased 329 γ in this interval. The disturbance was greatest between 02^h and 03^h during which time D had a range of 1° 05′ reaching an extreme westerly value at 02^h 47^m. A sharp depression in H occurred during the eighth hour of September 25 leading to a value of minimum H of 17,936 γ at 07^h 13^m. Minor disturbance continued until the end of the storm at 04^h, September 26. K-sums for September 24 and 25 were 39 and 42, respectively. K-indices for the five intervals between 18^h, September 24, and 09^h, September 25, were 6, 6, 8, 6, 7.

William E. Wiles, *Observer-in-Charge*

Tucson Magnetic Observatory
July to September, 1947

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or 7^h $23^m.3$ W. of Gr.)

July 17-20—A sudden increase of 18 γ in H beginning at 10^h 39^m GMT, July 17, probably was the beginning of a moderately severe storm, although the six and one-half hours immediately following the sudden commencement were quiet. Rapid changes in D and H were in evidence during the four hours beginning at 17^h 48^m, July 17. The balance of the storm was characterized only by moderately rough magnetic weather, ending about 16^h, July 20. Ranges: D, 23′; H, 193 γ; Z, 91 γ.

August 12-13—A mild storm began at 00^h 20^m GMT, August 12, and seemed to last about forty-eight hours, the greatest disturbance occurring during the first eleven hours. There were no outstanding characteristics.

August 15-21—A rapid increase of 88 γ in H, with accompanying disturbances in D and Z, beginning at 09^h 50^m GMT, August 15, marked the commencement of a moderately severe storm. Activity during the first fifteen hours was rapid but not of great range, except for an exaggerated diurnal variation, until H exhibited a four-hour bay beginning about 22^h, August 15. Following the bay, H made only a partial recovery. The traces continued to be generally rough, with a depressed H until the end of the storm during the second half of the Greenwich day August 21. Ranges: D, 30′; H, 290 γ; Z, 95 γ.

August 22-25—A sudden commencement at 09^h 11^m GMT, August 22, consisted of very rapid increase of 105 γ in H, a sudden increase of 2′.5 in eastward D followed immediately by a rapid decrease of 10′, and a disturbance in Z. The greatest ranges in D and H occurred during the following three hours. From 12^h, August 22, until 01^h, August 23, the traces showed rapid short-period oscillations having a saw-tooth appearance. General moderate roughness characterized the balance of the storm which ended about Greenwich noon, August 25. Ranges: D, 36′; H, 286 γ; Z, 84 γ.

September 2-4—At 23^h 26^m GMT, September 2, a sudden drop of 9γ in H followed immediately by a rapid increase of 48γ marked the sudden commencement of a moderate storm. Changes occurring between 06^h and 11^h, September 3, were rapid and, in H, of fairly large amplitude. The maximum value of H occurred at 08^h 10^m, and the minimum at 09^h 32^m. The second half of the Greenwich day September 3 was marked by irregular, very rapid oscillations of small to medium amplitude. Activity then decreased and the end of the storm came near the end of the day September 4. Ranges: D, 21′; H, 261 γ; Z, 54 γ.

September 5-8—A slight disturbance about 18^h GMT, September 5, marked the beginning of a moderate storm that seemed to increase its intensity gradually and to reach a peak of activity about the end of the day September 7. There were no outstanding characteristics except that the ranges were comparatively small and the disturbance ceased fairly suddenly about Greenwich noon, September 8. Ranges: D, 19′; H, 114 γ; Z, 49 γ.

September 11-19—A storm of only moderate intensity but long duration began at 16^h GMT, September 11. During the first thirty-two hours the variations were small and irregular. Beginning with the Greenwich day September 13, activity increased somewhat with longer-period oscillations (of the order of one cycle per hour) in evidence, and with a markedly depressed H. Toward the end of September 14 the variations became more irregular. During the second half of September 15 the disturbance decreased in intensity, and continued thereafter as a moderate, very irregular activity. The end of the storm was difficult to determine, but may have been during the day September 19.

September 22-23—A series of very irregular disturbances of moderate amplitude, possibly constituting a magnetic storm, began about 06^h GMT, September 22 and ended about 15^h, September 23.

September 24-26—A moderately severe storm began about 00^h GMT, September 24. Activity was irregular. During the nine-hour period following 23^h, September 24, there were several large swings in H and D. The chief characteristic of the storm seemed to be the unusually low average value of H between Greenwich noon, September 24, and noon, September 25. The intensity of the disturbance decreased after noon, September 25 and ended rather suddenly about 04^h, September 26. Ranges: D, 21′.5; H, 205 γ; Z, 75 γ.

J. H. Nelson, *Observer-in-Charge*

Alibag Magnetic Observatory

July to September, 1947

(Latitude 18° 38′.3 N., longitude 72° 52′.3 or 4^h $51^m.5$ E. of Gr.)

July 17-18—A storm of great intensity commenced suddenly at 17^h 48^m GMT, July 17, with an unusually large increase of 109 γ in H, a decrease of 27 γ in Z, and an increase of 1′.3 in westerly declination. After a period of

intense activity lasting for about three hours, all three elements became fairly steady until about $03^h\ 15^m$, July 18, when rapid fluctuations began to be recorded continuously until about $11^h\ 15^m$. A crochet of the type usually associated with a solar flare was also recorded on all the magnetograms at $10^h\ 37^m$, July 17. The storm ended at about 20^h, July 18, giving K-indices one each of 8, 7, and 6 and two of 5. Ranges: D, 8′.5; H, 298 γ; Z, 62 γ.

August 15-16—A "sudden-commencement" disturbance began at $09^h\ 50^m$ GMT, August 15, with a rise of 59 γ in H, a fall of 28 γ in Z, and an increase in westerly declination of 2′.1. The disturbance ended at about 24^h, August 16, giving one K-index of 7 and five of 5. Ranges: D, 10′.6; H, 264 γ; Z, 72 γ.

August 22-23—A storm of great intensity with a sudden commencement began with a *decrease* of about 2 γ, immediately followed by an increase of 64 γ in H, an *increase* of about 7 γ, immediately followed by a decrease of 32 γ in Z, a decrease in westerly declination of 0′.3, immediately followed by an increase of 2′.1, was recorded at $09^h\ 10^m$ GMT, August 22. H reached its maximum at $09^h\ 13^m$, after which it fell very rapidly until $10^h\ 26^m$, August 22, resulting in a fall of 287 γ in about an hour. Thereafter it began to fluctuate very rapidly until about 13^h, and then slowly recovered. All of the three elements recorded moderate-amplitude fluctuations continuously from about 03^h to 14^h, August 23. The storm ended at about $19^h\ 30^m$, giving one K-index of 8, one of 6, and one of 5. Ranges: D, 9′.0; H, 306 γ; Z, 87 γ.

September 2-4—An increase of 20 γ in H, decrease of 9 γ in Z, and increase of 1′ in westerly declination, marked the beginning of a sudden-commencement storm at $23^h\ 24^m$ GMT, September 2. The disturbance continued to be slight until about $05^h\ 30^m$, September 3, when all the elements recorded large fluctuations. H reached its maximum at $08^h\ 07^m$ and decreased very rapidly by jerks until $09^h\ 42^m$, September 3, when it again rose by jerks until $10^h\ 03^m$, after which it again fell. Similar jerks but in opposite directions were also as usual recorded simultaneously in Z. The storm ended at about 12^h, September 4, giving one K-index of 8, one of 7, and four of 5. Ranges: D, 14′.7; H, 373 γ; Z, 135 γ.

M. P. Rao, *Assistant*

Geophysical Institute of Huancayo

July to September, 1947

(Latitude 12° 02′.7 S., longitude 76° 20′.4 or $5^h\ 01^m.4$ W. of Gr.)

July 17—At $17^h\ 49^m$ GMT, July 17, a sharp increase in H of 260 γ in a five-minute period was noted, followed by a rapid decrease in intensity in the two and a half hours that followed to a minimum bay 620 γ below the maximum (which was registered at $17^h\ 54^m$, 460γ above the base-line value); this was followed by a moderate increase of 140 γ and a subsequent drop of practically the same magnitude in the next three hours, after which

H continued active (showing small, rapid movements, and two deep bays and one moderate peak during the course of the next day), and at a subnormal value, slowly returning to normal in the next seventy-two hours. At the time of commencement Z increased in value by 24 γ in a five-minute period, decreasing to a minimum 56 γ below the peak in the next two and a half hours. D showed a sharp but small increase at $17^h\ 49^m$ and a maximum range of $5'.5$ during the period of maximum activity.

August 1—At $15^h\ 18^m$ GMT, August 1, a very short, sudden-commencement storm was indicated by a sharp increase in H of 102 γ to an unusually high value for the maximum at this hour, 323 γ above the base-line value. This was followed by a rapid return to normal values in the next five hours, characterized by very moderate peaks and bays. Z also indicated a sharp increase at $15^h\ 18^m$ of 7 γ, but no after-effects. D, other than a slight increase at the time of the sudden commencement, was practically undisturbed.

August 12-15—At 00^h GMT, August 12, H decreased to a lower-than-normal value, slowly returning to normal by 12^h, August 13. H and D showed increased activity at that time. H was especially characterized during the period between 12^h and 21^h, August 13, by several peaks and bays, the most important of which was a drop at $16^h\ 55^m$ of 250 γ in a fifty-minute period. From 21^h, August 13, until $09^h\ 51^m$, August 15, H showed a tendency to return to normal activity and position, although it was recorded throughout the whole of this period at a lower-than-normal value.

August 15—At $09^h\ 51^m$ GMT, August 15, a sudden commencement in H indicated the beginning of a storm. In a two-minute period, H increased 40 γ, followed by sharp peaks and bays of moderate amplitude, slowly increasing in value. A maximum was obtained at $16^h\ 12^m$ (380 γ above the base-line value), and this in turn was followed by a similar series of peaks and bays, slowly decreasing in value. A minimum was reached at $23^h\ 12^m$ (240 γ below the base-line value). H remained disturbed during the days following (August 16-21), being characterized by abnormal activity during the daylight hours, and subnormal values and moderate activity during the night hours. At $09^h\ 51^m$, August 15, Z sharply increased by 10 γ, while D increased approximately $2'$. These elements were disturbed throughout the remainder of this day; thereafter D returned rapidly to normal, while Z recorded at a lower-than-normal position for several hours, gradually returning to normal.

August 22—At $09^h\ 11^m$ GMT, August 22, a sudden increase in H of 60 γ in a two-minute period indicated the beginning of another storm. This sudden increase was followed by further increase of H to a maximum at $09^h\ 18^m$, 88 γ above the base-line value, followed by a rapid decrease in intensity to a minimum at $10^h\ 36^m$, 289 γ below the base-line value—a range of 377 γ in a seventy-eight-minute period—and then followed very rapid, fairly large movements, slowly decreasing in amplitude and activity

by 24^h, August 22. From a lower-than-normal value *H* gradually returned to normal during the next four or five days. *D* was quite active during the twelve-hour period following the beginning of the storm, although the effect of the sudden commencement was very slight. *Z* showed an increase at the time of beginning ($09^h\ 11^m$) of 20 γ, and also continued active for the following twelve hours.

September 2-3—At $23^h\ 24^m$ GMT, September 2, *H* increased in a four-minute period by 42 γ. *Z* increased at this time by 10 γ, while the change in *D* was quite small although noticeable. This beginning was followed by a period of several hours of relative calm until $08^h\ 09^m$, September 3, when *H* dropped from a value of 110 γ above the base-line to a minimum at $09^h\ 17^m$, 134 γ below the base-line value. This drop was followed by peaks and bays of increasing amplitude as *H* increased in value to an unusually high maximum for this time of day (320 γ above the base-line value at $16^h\ 49^m$), and then the peaks and bays continued, gradually diminishing in proportions as *H* decreased in value. *H* remained noticeably active during the days that followed, practically throughout September 7.

September 11—A sudden-commencement type of storm of very short duration with no notable after-effects began at $15^h\ 58^m$ GMT, September 11, with a rapid increase in *H* and an immediate decrease to a deep bay. A range in *H* of 330 γ was recorded in the four-hour period that the storm lasted. Both *D* and *Z* showed the effects of the beginning of the storm, but otherwise no particular disturbance.

September 15—A sudden-commencement type of storm, similar to that of September 11, was indicated by an increase in *H* at $14^h\ 56^m$ GMT, September 15. *H* increased 285 γ in a four-minute period, followed by slow but fairly large peak-and-bay movements. The maximum range during the four-hour period that storm-effects were noticeable was 340 γ.

September 30—At $18^h\ 09^m$ GMT, September 30, there was a decrease in *H* of 34 γ, followed immediately by an increase of 150 γ, all in a five-minute period. This was followed by several small movements in the following three hours, and no notable effects thereafter. Both *Z* and *D* indicated the commencement. *D* particularly was disturbed at the time of beginning, decreasing at $18^h\ 09^m$ about $1'$ and immediately increasing about $3'$.

PAUL G. LEDIG, *Observer-in-Charge*

APIA OBSERVATORY

APRIL TO SEPTEMBER, 1947

(Latitude 13° 48′.4 S., longitude 171° 46′.5 or $11^h\ 27^m.1$ W. of Gr.)

April 8-10—A marked sudden commencement at $21^h\ 51^m$ GMT, April 8, was followed by mild irregular movement with a gradual return to normal at 09^h, April 10. *K*-indices of 5 were recorded during the last three-hour period of April 8 and the second of April 9.

April 17-24—A sudden commencement at 12^h 27^m GMT, April 17, introduced a stormy period. Rapid oscillatory movement with superposed bays and peaks became very marked at 18^h, April 17, and continued in a more moderate form from 00^h 08^m until 23^h, April 18. Mild activity persisted until 13^h, April 20. K-indices of 7 and 6 were recorded during the seventh and eighth three-hour periods, April 17.

May 13-16—Minor activity emerged at about 20^h GMT, May 13, and persisted with periods of quiescence until 12^h, May 17. Stronger movement followed a sudden commencement at 00^h 22^m, May 15, and continued until 09^h, May 16. Maximum K-index occurred during the last three-hour period April 13. K-index 4 was recorded during second three-hour period, April 15.

May 22-25—A sudden commencement at 22^h 43^m GMT, May 22, introduced a moderately disturbed period. Movement was characterised by fluctuations of an irregular nature. Maximum K-indices of 7 and 6 were recorded during the third and fourth three-hour periods, May 24, when a large negative bay developed. Activity quietened at 02^h 09^m, May 25, but the H-traces for several days following the storm were mildly disturbed.

May 31-June 1—Mild activity during May 31 became intensified at 16^h 30^m GMT, May 31, and continued until 10^h, June 1. K-indices of 5 were recorded during the first and fourth three-hour periods, June 1.

June 5-6—A sudden commencement at 07^h 30^m GMT, introduced an active period of short duration. Movement quietened at 02^h, June 6. Maximum K-index 6 was recorded during the third three-hour period, June 5.

June 13-18—A moderate disturbance began with a small sudden commencement at 17^h 48^m GMT, June 13. Movement quietened at 21^h 03^m, June 14. Maximum K-index 6 was recorded during the last three-hour period June 13. The trace remained mildly disturbed during June 15 and June 16, movement becoming stronger again at 03^h, June 17. Activity faded out at 11^h 21^m, June 18. K-indices of 5 were recorded during the second and third three-hour periods, June 17.

July 17-20—A sharp, sudden commencement at 17^h 05^m GMT, July 17, was followed by a period of mild activity. Movement in the initial stages consisted of small, rapid oscillations superposed on peaks and bays. Oscillatory movement abated at about 11^h, July 18, but the traces remained slightly disturbed until 15^h, July 20. K-indices of 5, 6, and 5 were recorded in the sixth, seventh, and eighth three-hour periods, July 17.

August 11-12—The trace became slightly disturbed at 02^h 47^m GMT, August 11. Stronger movement began at 00^h 21^m, August 12, and continued until 11^h 05^m, August 12. A maximum K-index of 5 was recorded during the first three-hour period, August 12.

August 15-27—A prolonged period of disturbance was introduced by a sudden commencement at 09^h 52^m GMT, August 15. H decreased rapidly

between 18^h 54^m, August 15, and 00^h 03^m, August 16, giving a *K*-index of 7 during the eighth three-hour period, August 15. Bay-like movement continued throughout August 18 and 19, and the traces remained mildly disturbed until 21^h 09^m, August 21. After a brief period of quiescence, a sudden commencement at 09^h 11^m introduced a severe disturbance of short duration. Irregular movement continued until about 15^h, August 23. The following days—August 24, 25, 26, and 27—were quiescent except for a slight tendency towards bay-like movement. A *K*-index of 8 was recorded during the fourth three-hour period, August 22, while a solar flare was very noticeable both in *H* and *Z* between 00^h, August 23, and 00^h 32^m, August 23. A *K*-index of 6 was recorded during the interval containing the solar flare.

September 2-4—A sudden commencement at 23^h 25^m GMT, September 2, introduced a moderate disturbance of short duration. *K*-indices of 7 and 6 were recorded during the third and fourth three-hour periods, September 3, the trace remaining disturbed until 19^h 39^m, September 4.

September 5-8—Minor activity occurred during the period commencing 20^h 12^m GMT, September 5, and ending 09^h 32^m, September 8. A *K*-index of 4 was recorded during the first three-hour period, September 6, the seventh period, September 7, and the first and third periods, September 8.

September 11-26—The whole of this period was characterized by bay-like movement. There was a tendency for both the *H*- and *Z*-traces to show a gradual decrease forming a negative bay followed by an increase, the minimum on several consecutive days occurring at approximately the same time. On September 12, 13 and 14, negative bays reached their minimum at 09^h, 08^h 31^m, and 09^h 28^m, respectively. A *K*-index of 4 was recorded during the third and fourth three-hour periods, September 12, and the second and fifth three-hour periods, September 13. A *K*-index of 5 occurred during the fourth and fifth three-hour periods, September 14. A negative bay developed on September 15 with a minimum at 10^h 15^m. A *K*-index of 5 was recorded during the fifth three-hour period, September 15. Slight activity of the same type persisted from September 16 to 22, when stronger movement again developed. Minima occurred at 10^h 17^m, September 22, and at 09^h 23^m, September 23. A *K*-index of 5 was recorded during the third and fourth three-hour periods, September 22, and the first, second, and fourth periods, September 23. Movement became more irregular and greater in amplitude at about 11^h, September 23, conditions finally returning to normal at 03^h 40^m, September 26. A maximum *K*-index of 6 was recorded during the third three-hour period, September 25.

J. W. Beagley, *Director*

Watheroo Magnetic Observatory

July to September, 1947

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or 7^h $43^m.5$ E. of Gr.)

July 17-18—A fairly severe storm commenced suddenly at 17^h 50^m GMT, July 17. H increased by 5 γ, then stopped momentarily, after which it increased by a further 82 γ in the next two minutes. After a slight decrease, there was another increase until the maximum of the storm was reached at 17^h 56^m. A general downward movement then set in until 23^h 13^m, when H reached almost its lowest point for the storm. At the commencement, D moved 4′ west very rapidly, then swung east through 17′ by 18^h 14^m, after which it moved west again. During this initial period Z increased by 12 γ in a minute, then decreased by 49 γ in the following three minutes, after which there was a further decrease until 18^h 14^m, when Z reached its minimum for the storm. The movements in all three elements were large and irregular until 24^h, July 17. Small, slow movements then followed until 03^h, July 18, when rapid variations of moderate intensity occurred in all elements. At times these were too rapid to record; they died out by 11^h 20^m. The subsequent movements were slow and irregular and they continued until 20^h, July 18, which may be taken as the end of the storm. The full range of Z cannot be determined because the Z-spot moved off the sheet from 14^h 28^m to 15^h 00^m, and again from 15^h 12^m to 15^h 25^m, both on July 18. Ranges: D, 24′; H, 208 γ; Z, >150 γ.

August 15-21—A moderate storm, which was followed by a prolonged period of mild disturbance, commenced suddenly at 09^h 51^m GMT, August 15, with an increase of 48 γ in H and smaller movements in D and Z. There followed a period of small, short-period fluctuations which continued into the middle of the following day. Between 21^h and 24^h, August 15, H decreased markedly and remained somewhat depressed until the end of August 21. Thereafter the variations were slow and of moderate amplitude. Conditions throughout the whole of the period of August 15 to 21 were moderately disturbed. The greatest range in H during this time occurred between a maximum at 21^h 09^m, August 15, and a minimum at 14^h 20^m, August 16. Ranges: D, 25′; H, 178 γ; Z, 149 γ.

August 22-23—A fairly severe disturbance commenced suddenly at 09^h 11^m GMT, August 22. The movements during the first three hours were very rapid, being at times too fast for the spots to record. On such occasions an interpretation was obtained from the la Cour quick-run record. H decreased suddenly by 6 γ and then increased by 54 γ, followed by a further rapid increase of 10 γ before commencing an equally rapid decrease which continued until 10^h 23^m. Then H suddenly increased by 215 γ in four minutes, reaching its maximum for the storm at 10^h 27^m. There followed a very rapid downward movement in three stages until H reached its mini-

mum at 10^h 46^m. There were further rapid fluctuations with smaller and slower movements setting in. Quiet conditions prevailed between 19^h 30^m and 24^h 00^m. Small, rapid fluctuations occurred on August 23 from 00^h onward and these became less marked by 08^h. There followed some moderate, slow-period movements which died out by 20^h, August 23, by which time the storm had ended. Both D and Z were markedly disturbed for the period of the storm, showing large, rapid variations during the first phase from 09^h 11^m to 13^h 00^m. The Z-spot moved off the edge of the paper on three occasions. The records of D and Z during the following thirty-one hours showed characteristics similar to those described above for H. A red auroral glow was observed to the south-southwest from Watheroo between 10^h 15^m and 10^h 30^m, August 22. Slightly disturbed conditions prevailed in all elements until the end of August 26. Ranges: D, 25′; H, 313 γ; Z, $>143\ \gamma$.

September 2-3—A fairly severe storm commenced at 23^h 26^m GMT, September 2, with a sudden commencement shown only in H. H increased 13 γ in a minute. At 23^h 15^m, D began to swing west, continuing until 23^h 29^m, with a total change of 5′. Z increased by 23 γ during the same time. The movements in all three elements were slight and irregular for the following six hours. Then at 05^h 45^m, they became more pronounced and for the next four and a half hours there were large, rapid fluctuations. H dropped very markedly during this time, the maximum and minimum for the storm being at 08^h 09^m and 10^h 08^m, respectively. Z increased slowly during the interval. All elements showed a rapid swing between 10^h 05^m and 10^h 13^m, H and D decreasing and Z increasing. Irregular movements continued with a general recovery until 20^h 20^m, September 3. H was still depressed slightly, but conditions had otherwise returned to normal by this time. Ranges: D, 35′; H, 290 γ; Z, 187 γ.

September 23-25—A moderate storm began at 23^h 53^m GMT, September 23, the commencement being more marked in D and Z than in H. The movements in all three elements were irregular and fairly rapid, although of small amplitude until 14^h, September 24, when they became slower and larger. At 22^h the fluctuations changed in character, becoming small and rapid. These conditions continued until 05^h, September 25, while H showed a continued downward trend. After 05^h, H began to rise again and during the following fifteen hours there were large, slow variations while conditions returned to normal. The storm was over by 20^h. Ranges: D, 20′; H, 228 γ; Z, 129 γ.

F. W. Wood, *Observer-in-Charge*

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